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THE ELEVENTH UK NATIONAL QUANTUM ELECTRONICS CONFERENCE

TECHNICAL DIGEST

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TECHNICAL DIGEST OF PAPERS

presented at

THE ELEVENTH UK NATIONAL QUANTUM ELECTRONICS CONFERENCE

30 August - 2 September 1993

at

THE QUEEN'S UNIVERSITY OF BELFAST

under the auspices of

The Quantum Electronics Group of the Institute of Physics

Organized by: The School of Mathematics and Physics,Queen's University,

Co-Sponsored by: The Institute of Electrical Engineers
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Billy Rea	-	Lecture Theatre and Audio-Visual

QE-11 PROGRAMME SUMMARY

TIME	SUNDAY 29th August	MONDAY 30th August	TUESDAY 31st August		WEDNESDAY 1st September		THURSDAY 2nd September	FRIDAY 3rd September
0845	EXCURSIONS TO MOURNES AND GIANTS CAUSEWAY	WELCOME						
0900		I.1 Mandel	I.6 Byer		I.10 Prior	EXHIBITION OPEN 0900 - 1400	I.15 Harris	Quantum Optics Workshop
0930					I.11 Tropper			
1000		I.2 Scully	I.7 Brown		Session 6 Oral (2)		I.16 Perry	
1030-1100		Coffee	Coffee	TECHNICAL EXHIBITION OPEN 1030 - 1800 and 2000 - 2200	Coffee		Coffee	Coffee
1100		Session 1 Oral (4)	I.8 Papuchon		I.12 Taylor		Session 9 Oral (4)	Quantum Optics Workshop
1130			Open Discussion (Sibbett)		Session 7 Oral (4)			
1200		I.3 Henderson					I.17 Lewis *END OF QE-11*	*END*
1230-1400		LUNCH	LUNCH		LUNCH		LUNCH	LUNCH
1400		I.4 Ironside	I.9 Thompson		I.13 Ippen		Quantum Optics Workshop	
1430		I.5 Eason	Session 4 Oral (4)		I.14 Willetts			
1500		Session 2 Oral (2)			TEA			
1530-1600		TEA	TEA		Session 8 (poster)			
1600		Session 3 (poster)	Session 5 (poster)					
1730 EVENING EVENTS	Informal University Reception and Registration (Halls)	Conference Banquet in City Hall	Exhibition Reception Whitla Hall		IDB Reception followed by Entertainment - Common Room			

CONFERENCE PROGRAMME

MONDAY 30 AUGUST 1993

0845 WELCOME

INVITED 1 **(Chairman: S E Barnett)**

0900 (1) **L Mandel** *University of Rochester*
Some new optical measurement techniques emerging from the quantum domain

INVITED 2

0945 (2) **M O Scully** *University of New Mexico, Albuquerque*
Atomic coherence in quantum optics: recent experimental and theoretical results

1030 **COFFEE SERVED IN SOUTH DINING HALL**

SESSION 1 ORAL NON-LINEAR OPTICS (Chairman: B Sinclair)

1100 (3) Studies of GaAs/AlGaAs multiple quantum well modulators using photon-counting techniques
Buller G S, Massa J S, Fancey S J and Walker A C *Heriot Watt University*

1115 (4) Continuous-wave lithium triborate optical parametric oscillators
Colville F G, Padgett M J, Henderson A J, Zhang J and Dunn M H
University of St Andrews

1130 (5) Application of asymmetric Fabry-Perot modulators to an optical neural network
Jennings A, Kelly B, Hegarty J and Horan P *Trinity College, Dublin*

1145 (6) Lowering of threshold due to formation of rolls in optical parametric oscillators
Oppo G-L *University of Strathclyde*
Brambilla M, Camesasca D, Gatti A and Lugiato L A *University of Milan*

INVITED 3 **(Chairman: B Sinclair)**

1200 (7) **B Henderson** *University of Strathclyde*
Crystal field engineering of tunable solid state laser gain media

1230 **LUNCH SERVED IN BEECH ROOM STUDENTS' UNION**

MONDAY 30 AUGUST 1993

INVITED 4 **(Chairman: J R M Barr)**

1400 (8) **C N Ironside** *University of Glasgow*
Ultrafast all-optical switching in semiconductor waveguides

INVITED 5

1430 (9) **R W Eason** *University of Southampton*
Photorefractive Waveguides

SESSION 2 ORAL SPECTROSCOPY (Chairman: J R M Barr)

1500 (10) Observations on a single trapped strontium ion using an all solid state system of lasers
Barwood G P, Edwards C S, Gill P, Klein H A , Rowley W R C
National Physical Laboratory

1515 (11) Frequency metrology using Ti:sapphire lasers
Bell A S, Riis E and Ferguson A I *University of Strathclyde*

1530 **TEA SERVED IN POSTER AREA, SOUTH DINING HALL**

SESSION 3 POSTER 1530 - 1730

Session 3A: Cavities/Propagation/Solitons

(12) Study of transverse effects in optical bistable ring resonators using the Finite Element Method
Buah P A, Rahman B M A and Grattan K T V *City University, London*

(13) Phase conjugation of copper vapour laser radiation using stimulated Brillouin scattering
Dutton R C *BNFL, Capenhurst*
O'Key M A and Osborne M R *Culham Laboratory*

(14) Pure helical laser modes
Harris M, Hill C A, Shepherd T J, Tapster P R, Vaughan J M
DRA, Malvern
Shackleton C J, Loudon R *University of Essex*

(15) Optical transmission properties of single crystal fibres
Renwick E K, Robertson E, Illingworth R and Ruddock I S
University of Strathclyde

MONDAY 30 AUGUST 1993

Session 3 POSTERS contd.

(16) Soliton dynamics in the presence of phase modulators
Smith N J and Firth W J — *University of Strathclyde*
Blow K J and Smith K — *BT Laboratories, Ipswich*

Session 3B: Fibre Lasers

(17) Erbium-doped fibre laser with frequency-shifted feedback
Barr J R M, Perry I R and Tropper A C — *University of Southampton*

(18) Thulium-doped lead germanate fibre lasers
Brinck D J B, Mackechnie C J, Wang J, Lincoln J R, Brocklesby W S, Tropper A C, Hanna D C and Payne D N — *University of Southampton*

(19) Narrow linewidth coupled cavity all fibre gratings lasers
Chernikov S V and Taylor J R — *Imperial College, London*
Kashyap R and McKee P F — *BT Laboratories, Ipswich*

(20) High repetition rate femtosecond soliton generation from an ytterbium-erbium fibre laser
Guy M J, Noske D U and Taylor J R — *Imperial College, London*

(21) Theory of FM mode-locked fibre lasers
Li J Y and New G H C — *Imperial College, London*
Smith K — *BT Laboratories, Ipswich*

(22) Multiphonon relaxation in low phonon-energy Pr^{3+} glasses
Naftaly M and Jha A — *Brunel University*
Hewak D W, Brocklesby W S, Samson B N, Doel R S and Payne D N — *University of Southampton*

(23) Operation of ytterbium-doped silica fibre lasers at specific wavelengths using fibre gratings
Pask H M, Archambault J L, Carman R J, Hanna D C, Mackechnie C J, Reekie L, Townsend J E and Tropper A C — *University of Southampton*

(24) Output characteristics of a xenon-ion laser pumped Ti:sapphire laser
Bocking S J, Latimer I D and Spoor S P — *University of Northumbria at Newcastle*

MONDAY 30 AUGUST 1993

Session 3 POSTERS contd.

Session 3C: Solid State Lasers

(25) Unidirectional Nd-doped phosphate glass ring laser using the acousto-optic effect in the laser medium
Clarkson W A and Hanna D C — *University of Southampton*
Lovering D S and Jones G C W — *Gooch and Housego Ltd, Ilminster*

(26) An investigation of the Q-switched Cr^{4+}:YAG laser system
Coleman F, Boyle A, Donegan J F and Hegarty J — *Trinity College, Dublin*
Eilers H, Dennis W M, Yen W M and Jia W — *University of Georgia, Athens*

(27) Beam combination by Raman techniques
Digman J R — *DRA, Fort Halstead*
Hollins R C — *DRA, Malvern*

(28) Original method for simultaneous measurement of the emission lifetime, gain and cross section at 1.06 and 1.3 microns in neodymium-doped optical waveguides
Dussardier B — *University of Southampton*
Pikhtin N — *A F Ioffe Physico-Technical Institute, St Petersburg*
Maurice E, Monnom G, De Micheli M, Saissy A and Ostrowsky D B — *Universite de Nice-Sophia Antipolis*

(29) Waveguide fluorescence spectra studies in ion-implanted Cr:$LiNbO_3$
Gallen N A — *University of Sussex*

(30) Diode laser pumped Nd:YAG mini slab laser and its frequency doubling
Hong J, Yelland C, Dunn M H, Sibbett W and Sinclair B D — *University of St Andrews*

Session 3D: Non Linear Optics

(31) A fast optical switch for high-power radiation
Aboites V, Baldwin K J, Crofts G J and Damzen M J — *Imperial College, London*

(32) The linear and non-linear optical properties of polydiacetylene thin films
Axon T L and Bloor D — *University of Durham*
Molyneux S, Kar A K and Sherrett B S — *Heriot Watt University*

MONDAY 30 AUGUST 1993

Session 3 POSTERS contd.

(33) Electron emission from selected metal surfaces by multiphoton absorption of Nd:YAG radiation
Birrell A R, Mason N J and Newell W R — *University College, London*

(34) Holographic recording in algal solutions
Brown K M, Cunningham A, Illingworth R, Lamb K, Ruddock I S and Russell D L — *University of Strathclyde*

(35) Optically-induced violation of time-reversibility in GaAs: probing by time-resolved micropolarimetry
Bungay A R, Malinowski A, Popov S V and Zheludev N I — *University of Southampton*
Paraschuk D — *Moscow State University*

(36) Photophysical and photochemical processes in fullerenes under high intensity illumination
Byrne H J, Maser W K, Kaiser M, Akselrod L, Anders J, Ruhle W W, Zhou X Q, Thompsen C, Mittleback A, Roth S — *MPI fur Festkorperforschung, Stuttgart*

(37) Multigigabits pulse source based on switching an optical beat signal in a nonlinear fibre loop mirror
Chernikov S V and Taylor J R — *Imperial College, London*

(38) Spontaneous spatial patterns in a lattice-like nonlinear Fabry-Perot etalon
Firth W J and Samson B A — *University of Strathclyde*

(39) An important paradox concerning reverse saturable absorption
Hughes S, Spruce G, Wherrett B S — *Heriot Watt University*
Welford K R — *DRA, Malvern*

(40) Linear/circular dichroism of two-photon absorption in zinc blende semiconductors
Hutchings D C — *University of Glasgow*
Wherrett B S — *Heriot Watt University*

(41) The use of laser photodetachment to characterize electronegative discharges
Al-Jibouri A and Graham W G — *Queen's University of Belfast*

MONDAY 30 AUGUST 1993

Session 3 POSTERS contd.

Session 3E: Laser Applications

(42) An EUV source based on a small scale laser produced plasma and multilayer filter combination
Collins M, Costello J T, Kennedy E T, Mosnier J-P, Shaw M — *Dublin City University*
Rivoira R — *Universite d'Aix Marseille III*
Barchewitz R — *Universite Pierre et Marie Curie, Paris*

(43) Surface plasmon enhanced laser ablation of thin metal films
Dawson P and Cairns G — *Queen's University of Belfast*

(44) Rapid photon correlation studies of relaxation in molecular films
Earnshaw J C and Sharpe D — *Queen's University of Belfast*

(45) Spectroscopic techniques for investigation and control of laser ablation plasmas
El-Astal A H, Graham W G, Ikram S, Morrow T, Sakeek H F and Walmsley D G — *Queen's University of Belfast*

(46) Ion emission studies of pulsed laser ablation
Lunney J G, Bakolias C, Enrech M and Lawler J F — *Trinity College, Dublin*

(47) Preparation and optical and magneto-optical characterisation of Ba-hexaferrite by laser ablation
Papakonstantinou P, Atkinson R, Salter I W — *Queen's University of Belfast*
Gerber R — *University of Salford*

(48) Short-pulse laser plasma interaction experiments at Imperial College
Riley D, Smith R A, Mackinnon A J, Willi O and Hutchinson M H R — *Imperial College, London*

(49) Beam transfer properties of hollow sapphire fibre for high quality CO_2 laser beams
Somkuarnpanit S, Su D, Jones J C D and Hall D R — *Heriot Watt University*

(50) The detection of sputtered particles using nonresonant multiphoton ionisation
Wang L, Nor R, Mouncey S P and Graham W G — *Queen's University of Belfast*

MONDAY 30 AUGUST 1993

Session 3 POSTERS contd.

Session 3F: Spectroscopy

(51) Linear and non-linear optical spectroscopy of metal derivatives of fullerenes
Callaghan J, Blau W, Weldon D N — *Trinity College, Dublin*
Cardin D J — *University of Reading*

(52) Broadband excitation and emission of surface plasmon polaritons
Dawson P — *Queen's University of Belfast*
Bryan-Brown G, Sambles J R — *University of Exeter*

(53) Er^{3+}-luminescence in laser doped silicon
Donegan J F, Dodd P, Lunney J G and Hegarty J — *Trinity College, Dublin*

(54) Temperature dependence of luminescence linewidth in a type II GaAs/AlAs superlattice
Heffernan J F and Hegarty J — *Trinity College, Dublin*
Planel R — *L2M-CNRS, France*

(55) A multi-laser, multi-channel spectrometer facility for the study of the inner-shell excitation of atoms and ions
Kiernan L, Costelo J, Koble U, Mosnier J-P, Sayyad H, Shaw M and Kennedy E T — *Dublin City University*
Sonntag B F — *Universitdat Hamburg*

(56) The growth and spectroscopic characterisation of inorganic crystals having the structure of calcium-gallium germanate doped with chromium ions
Macfarlane P I, Han T P J, Henderson B — *University of Strathclyde*
Kaminskii A A — *Academy of Sciences, Moscow*

TUESDAY 31 AUGUST 1993

SESSION ON OPTOELECTRONICS INTO 21ST CENTURY

INVITED 6 — **(Chairman: W Sibbett)**

0900 (57) **R L Byer** — *University of Stanford*
CW Optical Parametric Oscillators

INVITED 7

0945 (58) **R G W Brown** — *Sharp Laboratories of Europe Ltd, Oxford*
Optoelectronics R & D for the 21st Century

TUESDAY 31 AUGUST 1993

1030 **COFFEE SERVED IN EXHIBITION AREA**

INVITED 8 **(Chairman: W Sibbett)**

1100 (59) **M Papuchon** *Thomson-CSF, Orsay*
Activities in optics and optoelectronics at the central research laboratory

1145 OPEN DISCUSSION SESSION **(Chairman: W Sibbett)**

1230 **LUNCH SERVED IN BEECH ROOM, STUDENTS' UNION**

INVITED 9 **(Chairman: F O'Neill)**

1400 (60) **R C Thompson** *Imperial College, London*
Spectroscopy and laser cooling of trapped ions

SESSION 4 ORAL LASERS 1 **(Chairman: F O'Neill)**

1430 (61) High power cw slab-waveguide molecular lasers
Baker H J, Colley A D, Hall D R, Shackleton C J, Villareal F and Vitruk P P
Heriot Watt University

1445 (62) The CHIRP II high power excimer laser
Fieret J, Heath R, Osborne M R, Osbourn S J, Stamatakis T and Winfield R J
Culham Laboratory

1500 (63) Investigation of sub-threshold transverse laser modes
Harris M, Hill C A, Shepherd T J, Vaughan J M *DRA, Malvern*
Loudon R *University of Essex*

1515 (64) SPRITE - a very high brightness ultraviolet laser system
Lister J M D, Divall E J, Downes S W, Edwards C B, Hirst G J, Hooker C J,
Key M H, Ross I N, Shaw M J and Toner W T *Rutherford Appleton Laboratory*

1530 **TEA SERVED IN EXHIBITION AREA, WHITLA HALL**

TUESDAY 31 AUGUST 1993

SESSION 5 POSTER 1530 - 1730

Session 5A: Semiconductor Lasers

(65) Reflectance modulation properties of DBR surface emitting laser diodes

Avrutin E A	*A F Ioffe Physico-Technical Institute, St Petersburg*
Gorfinkel V B	*University of Kassel*
Luryi S	*AT & T Bell Laboratories, Murray Hill*
Shore K A	*Bath University*

(66) Modelocking and short pulse production in a multiple quantum-well laser diode by optical pulse synchronous pumping

Harley-Stead M, O'Gorman J and Hegarty J	*Trinity College, Dublin*
Hawdon B J	*University of Stuttgart*

(67) Carrier pinning by mode fluctuations in laser diodes

O'Gorman J	*Trinity College, Dublin*
Chuang S L	*University of Illinois at Urbana-Champaign*
Levi A F J	*AT & T Bell Laboratories, Murray Hill*

(68) Influence of spectral broadening on gain and recombination in short wavelength quantum well laser doides

Rees P, Summers H D, Hamilton R A H, Smowton P M and Blood P
University of Wales College of Cardiff

(69) Turn-on jitter of semiconductor lasers in short external cavities

Shore K A	*Bath University*
Hernandez-Garcia E and San Miguel M	*Univ de les Illes Balears, Palma*
Mirasso C R	*Universidad de Cantabria*

(70) Quantum well structures for sub-millimetre optical rectification and frequency doubling Shore K A *Bath University*

(71) Modified bandwidth K-factor due to parasitics in laser diodes

Wong Y C A and Shore K A	*Bath University*

TUESDAY 31 AUGUST 1993

Session 3 POSTERS contd.

Session 5B: Solid State Lasers

(72) Quasi-three-level laser operation of YB:YAG waveguides
Large A C, Hanna D C, Jones J K, Shepherd D P and Tropper A C — *University of Southampton*
Chandler P J, Townsend P D and Zhang L — *University of Sussex*
Chartier I, Ferrand B and Pelenc D — *Centre d'Etudes Nucleaires de Grenoble*

(73) The effect of residual spatial hole burning in unidirectional ring lasers
Martin K I, Clarkson W A, Neilson A B and Hanna D C — *University of Southampton*

(74) Optical spectroscopy of transition-metal-ion-doped materials for solid-state lasers
McBride P, Sherlock R, Glynn T J and Morgan G P — *University College, Galway*

(75) Frequency-shifted feedback in a Nd:YLF laser
Phillips M W, Liang G Y, Wang R L and Barr J R M — *University of Southampton*

(76) Scalable cw diode end-pumped Nd:YLF slab system
Rahliff C, Dunn M H, Sinclair B D and Sibbett W — *University of St Andrews*

(77) A 1.9 micron thulium doped lead germanate waveguide laser
Shepherd D P, Brinck D J B, Hanna D C, Payne D N, Wang J and Tropper A C — *University of Southampton*
Kakarantzas G and Townsend P D — *University of Sussex*

Session 5C: High-power and X-ray Lasers

(78) Studies of an injector-amplifier XUV laser system
Cairns G, Lewis C L S, MacPhee A and Neely D — *Queen's University of Belfast*
Holden M, Krishnan J, Tallents G J — *University of Essex*
Smith C G and Zhang J — *University of Oxford*
Key M H, Norreys P N — *Rutherford Appleton Laboratory*
Burge R E, Browne M T, Slark G E — *King's College, London*
Holden P B, Pert G J, Ramsden S A — *University of York*

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Session 5 POSTERS contd.

(79) Propagation of intense picosecond laser pulses in dense gases
Ciarrocca M, Hutchinson M H R, Marangos J P and Smith R A
Imperial College, London

(80) Ultra-short pulse amplification experiments on the Vulcan glass laser system
Danson C, Barzanti L, Damerell A, Dooley M, Edwards C, Hancock S, Key M, Mahadeo R, Miller M, Norreys P, Ollman C, Pepler D, Rodkiss D, Ross I, Smith M, Taday P, Toner W, Wigmore K, Winstone T and Wyatt R
Rutherford Appleton Laboratory
Chang Z — *Xian Inst of Optics & Precision Mechanics*
Luan S, Hutchinson M H, Mercer I, Smith R A and Zhou F
Imperial College, London

(81) Two dimensional modelling of Raman conversion
Moreira C A and New G H C — *Imperial College, London*

(82) Kinetic and optical properties of condensed matter interacting with ultra-short, ultra-strong laser pulses
Polishchuk A Y and Meyer-ter-vehn J — *MPI fuer Quntenoptik, Garching*

(83) High brightness KrF laser using chirped pulse amplification
Ross I N, Houliston J, Key M H, Hooker C J, Lister J M D, Hirst G J, Shaw M J and Damerell A R — *Rutherford Appleton Laboratory*
Evans J — *University of St Andrews*
Osvay K — *JATE University, Hungary*

(84) Focal intensity smoothing in the optical and x-ray domains using a binary phase zone plate array
Stevenson R M, Norman M J and Bett T H — *AWE PLC*
Pepler D, Danson C N and Ross I N — *Rutherford Appleton Laboratory*

(85) All-optical switching using a cascaded second order nonlinearity in semiconductor waveguides
Hutchings D C, Aitchison J S, Ironside C N, Arnold J M and Al-hemyari K
University of Glasgow

(86) Relativistic treatment of a classical hydrogen atom in an ultra-strong laser field
Keitel C H, Knight P L and Protopapas M — *Imperial College, London*
Burnett K — *University of Oxford*

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Session 5 POSTERS contd.

Session 5D: Nonlinear Optics

(87) A finite difference simulation of multiwave mixing in planar optical waveguides
Lambkin P and Blau W — *Trinity College, Dublin*

(88) Frequency doubling of CO_2 laser wavelengths into the mid-infrared
Mason P D and Gorton E K — *DRA, Malvern*

(89) Optical nonlinearities in dyes and liquid crystals
McEwan K J, Welford K R and Hollins R C — *DRA, Malvern*

(90) All-optical excitonic nonlinearities in a ZnSe/(Zn,Cd) Se multiple quantum well modulator structure
Merville C, Galbraith I, Kar A K, Wherrett B S, Wang S Y, Kawakami Y, Simpson J, Prior K A and Cavenett B C — *Heriot Watt University*

(91) Optical bistability and x-shaped hysteresis in laser diode amplifiers
Mitchell N F, O'Gorman J and Hegarty J — *Trinity College, Dublin*

(92) Reduction of saturation carrier density in a compressively strained asymmetric Fabry-Perot modulator
Moloney M H, Heffernan J F and Hegarty J — *Trinity College, Dublin*
Woodhead J and Grey R — *University of Sheffield*

(93) Contrasting routes for sum frequency mixing in sodium vapour
Moseley R R, Shepherd S, Sinclair B D and Dunn M H
University of St Andrews

(94) Nonlinear optical properties of a soluble form of polyisothionaphthene
Page H, Burbridge S, Drury A, Davey A P and Blau W
Trinity College, Dublin

Session 5E: Quantum Optics

(95) Violation of Bell's Inequality and single particles.
Barnett S M — *University of Strathclyde*
Phoenix S J D — *BT Laboratories, Ipswich*

(96) The atomic Aharonov-Casher effect
Barnett S M and Riis E — *Universiiy of Strathclyde*

(97) Laser induced continuum structures (LICS) and above threshold ionisation (ATI)
Dalton B J and Dutton M E StJ — *The University of Queensland*

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Session 5 POSTERS contd.

(98) Generating and detecting non-classical field states by conditional measurements
Garraway B M, Moya-Cessa H and Knight P L — *Imperial College, London*
Sherman B, Kurizki G — *Weizmann Institute of Science, Israel*

(99) Quantum phase distributions and quasi-probabilities
Garraway B M and Knight P L — *Imperial College, London*

(100) Stochastic simulations of dissipation in quantum optics
Garraway B M and Knight P L — *Imperial College, London*

(101) Dissipation effects on wave packets in level crossings
Garraway B M — *Imperial College, London*
Suominen K A — *University of Oxford*
Lai W K and Stenholm S — *University of Helsinki*

(102) Linear and nonlinear refractive indices for dielectrics in squeezed vacuua
Hassan S S — *Ain Shams University, Cairo*
Bullough R K and Batarfi H A — *UMIST*

Session 5F: Ultrafast Phenomena

(103) A cw mode-locked Cr^{4+}:YAG laser
Conlon P J, French P M W and Taylor J R — *Imperial College, London*

(104) Development of mode-locked sub-picosecond all solid state lasers operating at 1054 nm
Hughes D W, Barr J R M, Friel G J, Hanna D C and Majdabadi A A
University of Southampton

(105) Novel effects in reverse-saturable dyes, with theoretical interpretation to determine a comprehensive range of molecular lifetimes
Hughes S, Spruce G and Wherrett B S — *Heriot Watt University*
Welford K R — *DRA, Malvern*

(106) Self-mode-locking of a NaCl:OH^- colour-centre laser
Kennedy G T, Grant R S and Sibbett W — *University of St Andrews*

(107) Noncritically phase-matched, Ti:sapphire-pumped femtosecond optical parametric oscillator
Reid D T, Ebrahimzadeh M, Dudley J M and Sibbett W
University of St Andrews

TUESDAY 31 AUGUST 1993

Session 5 POSTERS contd.

(108) Sub-100 fs self-starting femtosecond solid-state Ci:LiSrAlF$_6$ lasers
Rizvi N H, Mellish R, Solis J F, French P M W and Taylor J R — *Imperial College*
Delfyett P J and Florez L T — *Bell Communications Research, Red Bank*

(109) Coupled-cavity mode locking using passive AlGaAs waveguides
Su Z, Grant R S, Kennedy G T and Sibbett W — *University of St Andrews*
Aitchison J S — *University of Glasgow*

WEDNESDAY 1 SEPTEMBER 1993

INVITED 10 — **(Chairman: J Hegarty)**

900 (110) **K A Prior** — *Heriot-Watt University*
Advances in II-VI blue diode lasers

INVITED 11

930 (111) **A C Tropper** — *University of Southampton*
Visible fluoride fibre lasers

SESSION 6 ORAL LASERS 2 — **(Chairman: J Hegarty)**

1000 (112) Injection seeding of an infrared optical parametric oscillator with a tunable diode laser
Gardiner T D, Milton M J T and Woods P T — *National Physical Laboratory*

1015 (113) A self-starting femtosecond Ti:sapphire laser with an intracavity multiple quantum well absorber
Mellish R, French P M W and Taylor J R — *Imperial College, London*

1030 **COFFEE SERVED IN EXHIBITION AREA, WHITLA HALL**

INVITED 12 — **(Chairman: D R Hall)**

1100 (114) **R Taylor** — *Imperial College, London*
Femtosecond solid state laser systems

WEDNESDAY 1 SEPTEMBER 1993

SESSION 7 ORAL LASERS 3 (Chairman: D R Hall)

1130 (115) Forced Q-switching of multi-contact InGaAsP lasers
Burns D and Sibbett W — *University of St Andrews*
Williams K A and White I H — *University of Bath*
Fice M J — *BNR Europe Ltd, Harlow*

1145 (116) A laser diode pumped optical amplifier in the first telecommunications window
Lauder R D T, Hanna D C, Tropper A C, Pask H M, Carter J N — *University of Southampton*
Davey S T and Szebesta D — *BT Laboratories, Ipswich*

1200 (117) A laser diode pumped, Nd:YVO_4/KTP, frequency doubled, composite material microchip laser
MacKinnon N and Sinclair B D — *University of St Andrews*

1215 (118) An all-solid-state synchronously pumped optical parametric oscillator
McCarthy M J, Butterworth S D and Hanna D C — *University of Southampton*

1230 **LUNCH SERVED IN BEECH ROOM, STUDENTS' UNION**

INVITED 13 (Chairman: A G Roddie)

1400 (119) **E P Ippen** — *Massachusetts Institute of Technology*
Femtosecond studies of opto-electronic materials and devices

INVITED 14

1445 (120) **D V Willetts** — *DRA, Malvern*
Doppler Wind lidar for space applications

1515 **TEA SERVED IN POSTER AREA, SOUTH DINING HALL**

WEDNESDAY 1 SEPTEMBER 1993

SESSION 8 POSTER 1515-1730

Session 8A: Gas Lasers

(121) CO_2 waveguide laser arrays phase-locked by waveguide-confined tablot imaging
Baker H J, Colley A D, Hall D R and Hornby A M
Heriot Watt University

(122) The effects of air contaminants on XeCl laser performance
Gabzdyl J, Cleaver K and Stevenson A — *BOC Ltd, London*
O'Key M A and Osborne M R — *Culham Laboratory*

(123) Hysteresis effects in laser mode hops
Harris M, Shepherd T J and Vaughan J M — *DRA, Malvern*
Loudon R — *University of Essex*

(124) Optical measurements of excimer laser current pulse
Hodgson E, Boardman A D, Hua Y and Wilson A
University of Salford

(125) 155W average power copper hybrid laser
Jones D R, Maitland A and Little C E — *University of St Andrews*

(126) Longitudinal mode separation tuning in 633nm helium neon lasers using induced cavity birefringence
Oram R J, Latimer I D and Spoor S P — *University of Northumbria at Newcastle*

(127) Line-tunable molecular beam iodine laser from 526 nm - 1348 nm
O'Shaughnessy S M and Laine D C — *Keele University*

(128) Relations between preionization density distribution, electrode design and efficiency in high-pressure discharge-excited gas-lasers
Turner M M — *Dublin City University*

(129) Beam quality characteristics of a fast-axial-flow carbon monoxide laser
Yu G, Baker H J and Hall D R — *Heriot Watt University*

Session 8B: Nonlinear optics

(130) Breaking of the translational symmetry for pattern formation in Kerr media
Papoff F, D'Alessandro G, Oppo G-L and Firth W J
University of Strathclyde

(131) Near infrared optical nonlinearities in amorphous chalcogenides
Rangel-Rojo R, Kar A K and Wherrett B S — *Heriot Watt University*
Kosa T, Hajto E, Ewen P J S and Owen A E — *Edinburgh University*

WEDNESDAY 1 SEPTEMBER 1993

Session 8 POSTERS contd.

(132) Third order nonlinearities of TEA $(TCNQ)_2$ doped polymer films
Rangel-Rojo R, Kar A K and Wherrett B S — *Heriot Watt University*
Carroll M and Cross G H — *University of Durham*

(133) Low threshold operation of an all solid state KTP OPO
Terry J A C, Rae C F and Dunn M H — *University of St Andrews*

(134) Instabilities in modulated lasers
Turovets S I and Samson A M — *Academy of Sciences of Belarus Minsk*

(135) Measurement of the non-linear refractive index of gases at 248 nm
Wilson D C — *Imperial College, London*
Hooker C J and Shaw M J — *Rutherford Appleton Laboratory*

(136) Nonlinear propagation of partially polarized light
Zheludev N I — *University of Southampton*
Svirko, Yu P — *General Physics Institute, Moscow*

Session 8C: Quantum Optics

(137) Absorption and emission spectra of trapped two-level ions in the Lamb-Dicke limit
MacKay P E and Oppo G-L — *University of Strathclyde*

(138) Green's function theory of the parametric oscillator
Mertens C J and Kennedy T A B — *Georgia Institute of Technology*
Swain S — *Queen's University of Belfast*

(139) Three-level atom in a squeezed vacuum
Smart S and Swain S — *Queen's University of Belfast*

(140) Non-diffusive phase dynamics from linear amplifiers and attenuators
Vaccaro J A and Pegg D T — *Griffith University, Australia*

(141) Two-mode squeezed gaussons
Yeoman G and Barnett S M — *University of Strathclyde*

WEDNESDAY 1 SEPTEMBER 1993

Session 8 POSTERS contd.

Session 8D: Electro-optic Devices and Optoelectronics

(142) Calculations and experiments on radiatively coupled surface plasmon polaritons in real device geometries
Dawson P, Connolly M P and Whitaker M A B *Queen's University of Belfast*

(143) Tolerence analysis of the symmetric self-electro-optic-effect device within cascaded digital optical arrays
Desmulliez M P Y, Wherrett B S and Snowdon J F
Heriot Watt University

(144) Post-growth improvement of asymmetric Fabry-Perot modulator characteristics
Kelly B and Hegarty J *Trinity College, Dublin*
Horan P *Trinity College, Dublin*
Corbett B *NMRC, Cork*
Ghisoni M *University College London*

(145) The formation of ohmic contacts to ZnS thin films
Ma J, Molloy J, McLaughlin J, Maguire P and Laverty S
University of Ulster

(146) The Cu_xS-ZnS system in electroluminescent devices
Macken D, Molloy J, McLaughlin J, Maguire P and Laverty S
University of Ulster

(147) Pockels effect in ASFP MQW modulators
Marques M A *INESC, Portugal*
Vickers A J *University of Essex*

(148) Properties of ZnS:Mn thin films prepared by 248 nm pulsed laser deposition
McLaughlin J, Molloy J Anderson J, Maguire P and Laverty S
University of Ulster
El-Astal A H, Graham W G and Morrow T *Queen's University of Belfast*

(149) The electronic structure and transport properties of ZnS
Molloy J, Ma J, McLaughlin J, Maguire P and Laverty S
University of Ulster

(150) Tolerance advantages of differential over single optical logic elements
Waddie A J, Desmulliez M P Y and Snowdon J F
Heriot Watt University

(151) Asymmetric Fabry-Perot electro-optic modulators containing a polymeric film
Wang C H, Lloyd A D and Wherrett B S *Heriot Watt University*
Bone D J, Harvey T G, Ryan T G and Carter N *ICI plc, Wilton*

Session 8 POSTERS contd.

(152) Optical and magneto-optical properties of MBE grown Co/Au multilayers
Atkinson R, Hendren W R and Salter I W — *Queen's University of Belfast*

(153) Thermooptic deflection switching in polymeric optical waveguides
Cazzini K H, El-Akkari F R and Blau W — *Trinity College, Dublin*

(154) Theoretical study of carrier enhanced refractive nonlinearities in an InGaAsP/InP multi-quantum well all-optical phase modulator
Day I E, Penty R V and White I H — *University of Bath*

(155) Interferometric fibre optics sensor based on dispersive fourier transform
Flavin D A — *Waterford Regional Technical*
McBride R and Jones J D C — *Heriot Watt University*

(156) Strain-balanced InGaAs/GaAs SEED modulators for 1047 nm
Goodwill D J, Walker A C and Desmulliez M P Y — *Heriot Watt University*
Stanley C R, Holland M C and McElhinney M — *University of Glasgow*

(157) Nonlinear joint transform correlation with a GEC-Marconi optically addressed spatial light modulator
Lowans B S — *Short Brothers PLC, Belfast*
Bates B, Greer R G H — *Queen's University of Belfast*

(158) Optical and electro-optical synchronisation using laser diodes
Pelan P, Farrell G, Egan A, Hegarty J — *Trinity College, Dublin*
Shields J — *Northern Telecom (NITEC), Belfast*

(159) AlGaAs-GaAs heterostructures and resonant tunneling diodes: Current-voltage-temperature measurements and applications
Sellai A — *Queen's University of Belfast*
Raven M S — *University of Nottingham*

(160) Novel algorithms based on neutral networks may be used to efficiently exploit optical hardware characteristics
Snowdon J F and Waddie A J — *Heriot Watt University*

WEDNESDAY 1 SEPTEMBER 1993

Session 8 POSTERS contd.

Session 8E: Spectroscopy

(161) Raman scattering studies of the $(Al_xGa_{(1-x)})_{0.5}In_{0.5}P$ Alloy
O'Connor G M, Glynn T J and Morgan G P — *University College Galway*
Considine L and Lambkin J D — *NMRC, Cork*

(162) Investigation of trapped ion dynamics by photon correlation and pump-probe techniques
Segal D M, Horvath G Zs K, Dholakia K, Power W and Thompson R C
Imperial College, London

(163) Picosecond time-resolved resonance Raman spectroscopy in the study of vibrational mode-selective effects of singlet excited trans-stilbene
Towrie M, Matousek P, Parket A W and Toner W T
Rutherford Appleton Laboratory
Hester R E and Moore J N — *University of York*

(164) Luminescence measurements on conjugated organic materials
Winkler H and Blau W J — *Trinity College, Dublin*

(165) A fluorescence-line-narrowing study of porous Si
Xing J, Donegan J F and Hegarty J — *Trinity College, Dublin*

THURSDAY 2 SEPTEMBER 1993

INVITED 15 **(Chairman: P L Knight)**

0900 (166) **S E Harris** — *University of Stanford*
Electromagnetically induced transparency

INVITED 16

0945 (167) **M D Perry** — *Lawrence Livermore National Laboratory*
The development of ultrahigh power subpicosecond lasers

1030 **COFFEE SERVED IN SOUTH DINING HALL**

THURSDAY 2 SEPTEMBER 1993

SESSION 9 ORAL QUANTUM OPTICS (Chairman: G H C New)

1100 (168) Quantum propagation through linear devices
Jeffers J and Barnett S M — *University of Strathclyde*

1115 (169) On the origin of lasing without inversion
Keitel C H — *Imperial College, London*
Kocharovskaya O A — *USSR Academy of Science, Nizhmy Novgoad*
Narducci L M — *Drexel University, Philadelphia*
Scully M O — *Texas A & M University, College Station*
Zhu S-Y — *Shanghai Jiao Tong University*
Doss H M — *Mississippi State University*

1130 (170) Dispersive profiles in the resonance fluorescence of a two-level atom in a squeezed vacuum
Smart S, Smyth W and Swain S — *Queen's University of Belfast*

1145 (171) Ultra-high harmonic generation experiments at Imperial College
Smith R A, Tisch J W G, Ciarrocca M, Augst S, Muffett J, Marangos J P and Hutchinson M H R — *Imperial College, London*

INVITED 17 (Chairman: G H C New)

1200 (172) **C L S Lewis** — *Queen's University of Belfast*
X-ray lasers - progress and prognosis

1230 *END OF QE11*

1230 **LUNCH SERVED IN BEECH ROOM, STUDENTS' UNION**

1400 ***START OF QUANTUM OPTICS WORKSHOP***

Some New Optical Measurement Techniques emerging from the Quantum Domain

L. Mandel

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University of Rochester
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U.S.A.

Abstract

Some recent experimental work on one-photon and two photon interference, although concerned with fundamental questions, incidentally provides us with several new measurement techniques. These include a new method for measuring the time separation between two similar light pulses to an accuracy of ~ 10^{-15} sec, when each pulse consists of 1 photon. The method can be adapted to detect beats between two light beams by photoelectric measurement, even when the beat frequency exceeds the maximum detector frequency response a million times. The method can also be used to measure very short (sub-picosecond) coherence times. Finally, a new quantum technique for accurately controlling the degree of mutual coherence between two light beams, without affecting their intensities, will be described.

This research was supported by the NSF and the ONR.

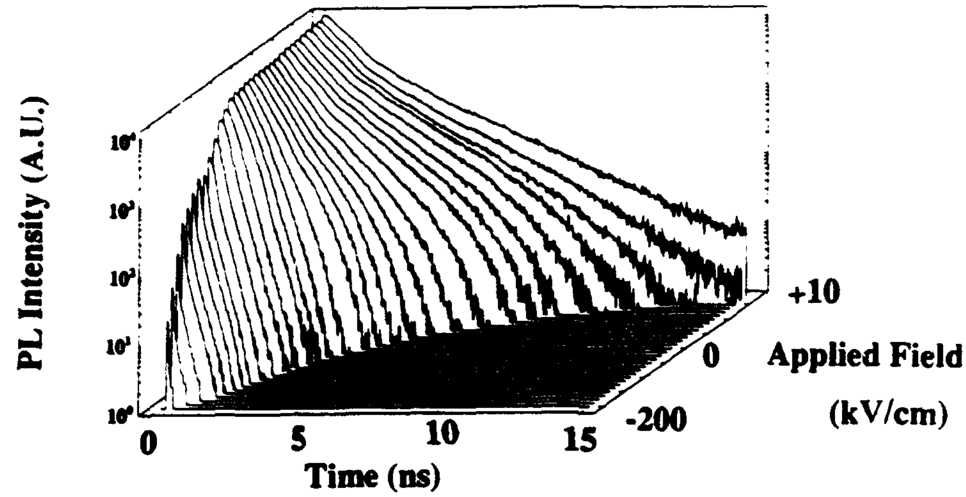

Fig. 1 Time-resolved photoluminescence decays of a GaAs/AlGaAs MQW modulator under different bias conditions.

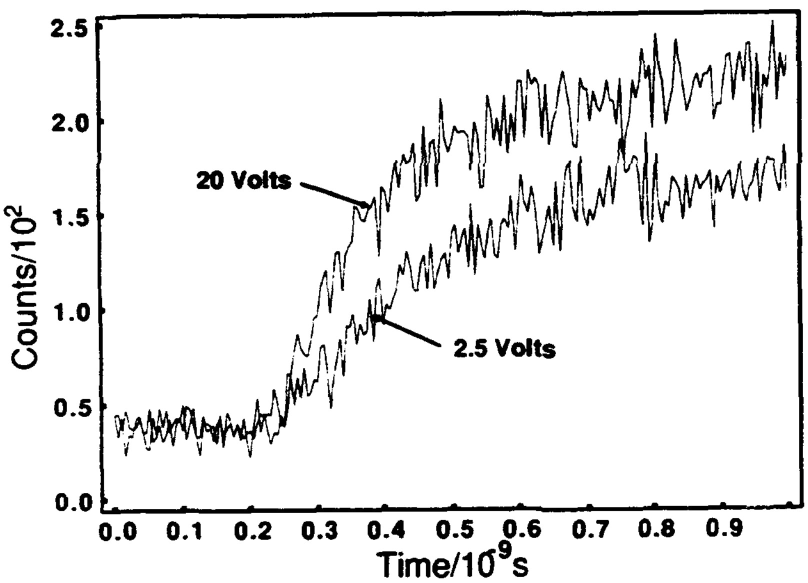

Fig. 2 Time-resolved switching of an S-SEED, at applied reverse bias of 2.5V and 20V.

STUDIES OF GaAs/AlGaAs MULTIPLE QUANTUM WELL MODULATORS USING PHOTON-COUNTING TECHNIQUES

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Department of Physics
Heriot-Watt University
Riccarton
Edinburgh
EH14 4AS

A key component of several opto-electronic devices (eg modulators, SEEDs, detectors, etc.) is the reverse-biased p-i-n multiple quantum well (MQW) structure. A fundamental limitation on the speed of such devices is the carrier sweep-out time. We present measurements and analysis of the carrier dynamics in such biased modulators using picosecond time-resolved photoluminescence techniques. The measurements were performed with an adapted optical microscope, using a passively Q-switched picosecond laser diode as the excitation source. A small-area silicon single-photon avalanche diode detector, with a rise-time of <20ps, was used in conjunction with the time-correlated single-photon counting technique. Figure 1 shows PL decays from a GaAs/AlGaAs multiple quantum well modulator as a function of reverse bias electric field. A discussion of the implications of such results on electro-absorption saturation, and the effects of Coulomb screening and carrier trapping will be presented.

A notable device which utilises two such MQW p-i-n diodes connected in series is the Symmetric-SEED (S-SEED). The switching speed of this is limited by a combination of RC electrical time constants and the above MQW carrier transport effects. By using an adapted pump-probe technique, the single-photon detection system was used to probe the reflection from one window of an S-SEED and hence measure its switch speed. Such a detection system meant that switching times as short as ~20ps could be resolved using this instrument. Figure 2 shows an example of the dynamic switching characteristics of an S-SEED at two different bias voltages. Discussions on the instrumental performance (eg temporal dynamic range, spatial resolution, etc.) will be presented, as well as the application of such techniques to other SEED derivatives, such as FET-SEEDs.

F. G. Colville et al., "Continuous-wave lithium triborate optical parametric oscillators"

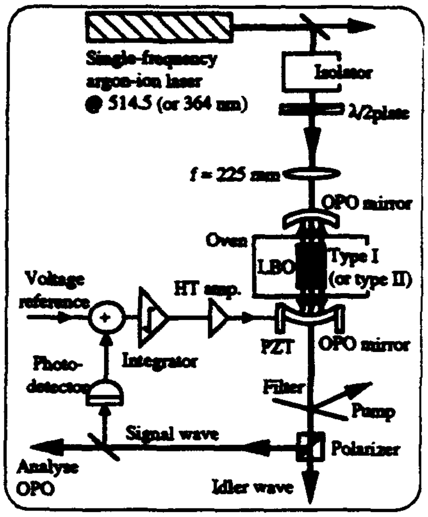

Fig. 1. Experimental arrangement.

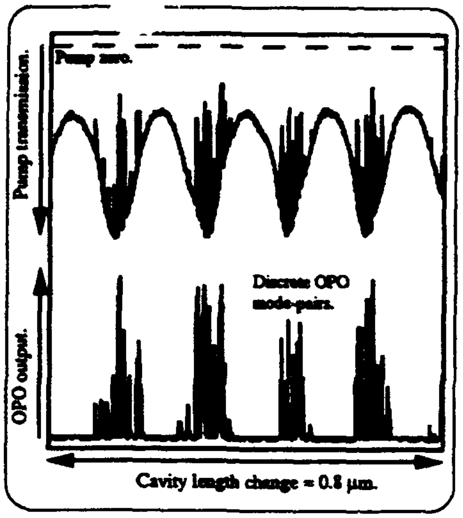

Fig. 2. Discrete mode-pairs every 5 - 7 nm.

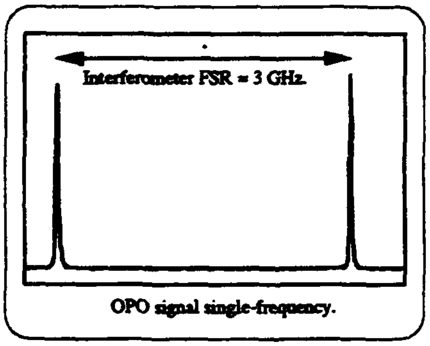

Fig. 3. Stable single-frequency OPO output.

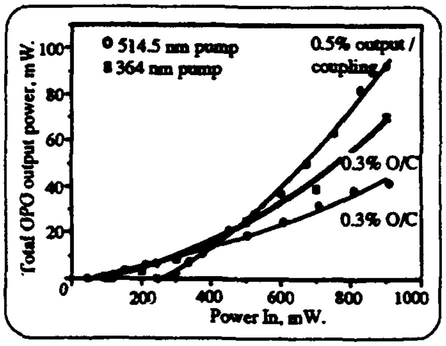

Fig. 4. OPO output powers.

Continuous-Wave Lithium Triborate Optical Parametric Oscillators

F. G. Colville, M. J. Padgett, A. J. Henderson, J. Zhang, & M. H. Dunn
J. F. Allen Physics Research Laboratories, Department of Physics & Astronomy
University of St. Andrews, North Haugh, St. Andrews, Fife, KY16 9SS, Scotland

WE have operated continuous-wave optical parametric oscillators (cw OPOs) using LBO as the nonlinear material. Its high damage threshold and wide transparency range make it an ideal choice for cw OPOs. Previously, cw OPO pump sources have been confined to the spectral region 488 - 532 nm. Our OPOs have been pumped by argon-ion lasers, both in the green[1] *and* the ultraviolet spectral regions. We report what we believe to be the *first* cw OPOs to use LBO, and the *first* UV-pumped cw OPO. Pumped in the green at 514.5 nm, temperature tuning is around degeneracy, from 0.97 to 1.1 μm. Pumped in the UV at 364 nm, we obtain stable single-frequency output from the OPO, with tuning from 502 - 494 nm (signal) and 1.32 - 1.38 μm (idler)[2].

The experimental arrangements are shown in fig. 1. Single lenses mode-match the pumps into the OPO cavities. The LBO crystals (length 20 mm) are cut for noncritical phase-matching (NCPM), and have triple-AR coatings applied to both faces (> 99.7% transmitting at the OPO wavelengths and > 97% at the pump). The OPO cavities are formed by two 15-mm-curvature mirrors separated by ≈ 22 mm, placed symmetrically about the crystals which are held in ovens to allow temperature tuning. The OPOs employ linear, standing-wave cavities. Both sets of OPO mirrors are ≈ 55% reflecting at the pump and > 99.7% reflecting at both OPO wavelengths. The experimental thresholds are found to be ≈ 50 mW (green pump) and ≈ 100 mW (UV pump).

As the cavity lengths are altered, the OPO output modulates due to competition between different signal and idler mode-pairs. For doubly-resonant oscillators, small changes in either cavity length or pump frequency cause mode-hops to adjacent mode-pairs / clusters. For the near-degenerate, green-pumped OPO, sub-nm cavity length changes can cause hopping. However, the UV-pumped OPO operates far from degeneracy, substantially relaxing these stability requirements. This is seen in fig. 2, which displays hopping at cavity length changes of between 5 - 7 nm.

For a mode-pair at 502 / 1320 nm, the free spectral ranges are mis-matched by ≈ 3%, for which the measured length changes are consistent with hopping to an adjacent mode-pair in the same cluster. Using a simple servo-loop, we obtain stable single-frequency output despite a relatively unstable pump source (± 10 MHz), as shown in the interferometer trace (fig. 3). A maximum of 103 mW total OPO output (signal + idler) is obtained for a pump power of 1.1 W. (The power ouput from both the OPOs is displayed in fig. 4.)

Such cw OPOs, which can operate single-frequency with widely spaced signal and idler frequencies, are attractive sources for optical frequency division[3] for which narrow linewidth radiation is required over a comb of frequencies covering the entire optical region. At ≈ 175 °C, the UV-pumped OPO would emit frequencies in an exact 3 : 1 ratio. This type II geometry also allows polarization decoupling of the signal and idler cavities with the prospect of then obtaining smooth and continuous tuning; we are currently exploring such opportunities.

References :
[1] F. G. Colville *et al.*, Opt. Lett. **18**, 205 (1993).
[2] F. G. Colville *et al.*, Opt. Lett. (to be published, 1993).
[3] N. C. Wong, Opt. Lett. **17**, 1155 (1992).

APPLICATION OF ASYMMETRIC FABRY-PEROT MODULATORS TO AN OPTICAL NEURAL NETWORK

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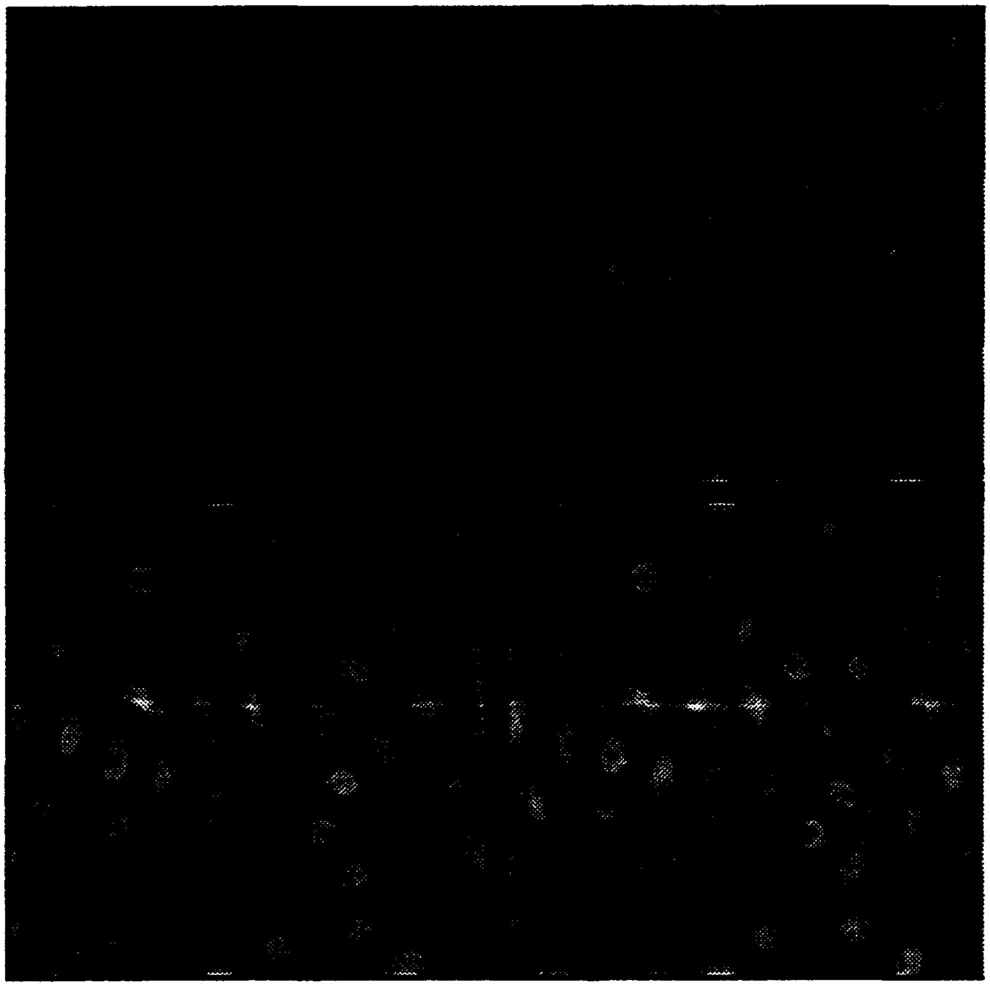
Paul Horan
Hitachi Dublin Labs., Trinity College, Dublin 2, Ireland.

Asymmetric Fabry Perot Modulators (AFPM) have been shown to display excellent characteristics as electro-optical switching devices. Attributes such as high contrast ratio, high speed, low insertion loss and low operating voltage have been shown in discrete devices (eg ref.1). For applications such as optical interconnection and processing, uniform arrays of devices are required.

We report on the fabrication of AFPM arrays and their successful implementation in an optical neural network system[2]. Linear arrays of normally 'on' AFPM devices which show very high uniformity have been fabricated[3]. A contrast ratio of 22±2 and insertion loss of 1.8±0.2dB have been measured across one array which has a total area of $6mm^2$.

Having fabricated AFPM arrays, the spatial light modulators have been used to implement an optical second order neural network capable of pattern recognition with translation invariance. A linear AFPM array presents an optical input pattern to the network and is used to carry out vector-vector multiplication. A second array is used to implement weighted interconnects. The neural network system has been built and shown to perform recognition with 100% translation invariance and good tolerance to input noise.

References:
1. K-K Law, M. Whitehead, J.L. Merz and L.A. Coldren, "Simultaneous achievement of low insertion loss, high contrast and low operating voltage in asymmetric Fabry-Pérot reflection modulator", Electron. Lett. 27, pp1863-1865, 1991.
2. P. Horan, A. Jennings, B. Kelly and J. Hegarty, "Optical Implementation of a Second Order Translation Invariant Network Algorithm", To be published in a special issue on *Optical Neural Networks*, App. Opt., 32(8), 1993.
3. A. Jennings, P. Horan, B. Kelly and J. Hegarty, "Asymmetric Fabry-Pérot Device Arrays with Low Insertion Loss and High Uniformity",Photonics Tech. Lett. 4, (8), pp858-860, 1992.



LOWERING OF THRESHOLD DUE TO FORMATION OF ROLLS IN OPTICAL PARAMETRIC OSCILLATORS

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M. Brambilla, D. Camesasca, A. Gatti, and L.A. Lugiato
Department of Physics, University of Milan
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A model for the formation of patterns for an Optical Parametric Oscillator (OPO) in a cavity is analysed. Diffractive effects due to the propagation in the cavity are considered for the degenerate case where the frequencies of the signal and idler are considered equal. By generalising the model introduced in Ref. [1], we perform the stability analysis for the uniform states below the usual OPO threshold. The solution with zero amplitude for the OPO signal is found to be unstable to periodically modulated perturbations whenever the signal/idler frequency is smaller than half of the input pump frequency. The unstable wave vector which characterises the spatially modulated solution is determined and an analytical form for the rolls close to threshold is obtained. The analytical solutions are compared with simulations for a wide range of input amplitudes and an excellent agreement is found. The threshold for the roll solution is much lower than the usual OPO threshold obtained in the plane wave limit, especially if the OPO signal is strongly detuned from half of the pump frequency. The inclusion of transverse effects leads to a more efficient use of the parametric conversion and can have important consequences on the experimental side.

The included figure shows four snapshots of the evolution of the intensity distribution on the plane transverse to propagation for the OPO signal at input amplitude three times above the roll threshold. The underlying presence of the roll structure is evident. Moreover, a secondary instability leading to zig-zag patterns has taken place and the system tries to recover both the translational and the cylindrical symmetries broken by the formation of rolls. This leads to the formation of intensity peaks as clearly shown in the last panel of the figure. An analysis of the pattern formation in terms of symmetries [2] is presently under consideration.

The presentation is implemented with the use of colour video cassettes for the visualisation of the spatiotemporal dynamics.

References.

1. P.D. Drummond, K.J. McNeil, and D.F. Walls, *Opt. Acta* **27**, 321 (1980).
2. F. Papoff, G. D'Alessandro, G.-L. Oppo, and W.J. Firth, *Phys. Rev. A* submitted (1993).

CRYSTAL FIELD ENGINEERING OF TUNABLE SOLID STATE LASER GAIN MEDIA

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Glasgow, G4 ONG, Scotland.

The first operational laser used a crystal of ruby, Cr^{3+}-doped sapphire (Al_2O_3), as the gain medium to achieve amplified stimulated emission at λ = 694nm. Since that time there have been hundreds of other demonstrations of solid state laser action involving rare earth ions, transition metal ions or colour centres in ionic crystals as the optically-active entity associated with laser action. The nature of the laser output (tunability, efficiency, tuning range, etc.) is determined in large measure by the interaction of the optical centre and its immediate environment. Local symmetry and the strength of the electrostatic crystal field and electron-electron interactions are of considerable importance but so too are the roles played by static or dynamic distortions in broadening spectra and contributing to transition rates.

The importance of engineering the crystal field to achieve laser output over particular wavelength ranges, matched to appropriate pump sources and with improved efficiency will be discussed using as examples transition metal ions Ti^{3+} and Cr^{3+}. The property changes introduced by static and dynamic crystal field interactions will be discussed by reference to certain families of ionic crystal hosts, e.g. garnets, colquirites ($LiCaAlF_6$) and the gallogermanates. Extension of the simple ideas of crystal field engineering from laser hosts to nonlinear optical materials will be discussed.

ULTRAFAST ALL-OPTICAL SWITCHING IN SEMICONDUCTOR WAVEGUIDES

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Abstract

Broad bandwidth all-optical communication networks capable of 100s of gigabits data rates will require new developments in ultrafast all-optical switches. These switches currently employ high-speed low-loss optical nonlinearities in guided wave format. Ultrafast all-optical switches can be made with optical fibre technology because of their exceptionally low linear and nonlinear optical losses. However, because of the small optical nonlinearity of optical fibres long lengths of fibre, of the order of several kilometres are required for switching devices. In this paper we review another approach to ultrafast all-optical switching which employs semiconductor waveguides where the optical nonlinearity and loss characteristics have been optimised so that relatively compact switches can be fabricated. Both second order ($\chi^{(2)}$) and third order ($\chi^{(3)}$) optical nonlinearities are available in semiconductor waveguides. Here we present results on third order optical nonlinearities and discuss how the second order optical nonlinearity may be employed in all-optical switching.

The recent theory (1) has indicated $\chi^{(3)}$ optical nonlinearites can be optimised by operating at photon energies just below half the band-gap energy where, crucially, two-photon absorption can be avoided. By employing this theory we have demonstrated ultrafast all-optical switching in nonlinear directional couplers(2) and interferometers(3). High-speed demuliplexing has been demonstrated with a 2 cm long nonlinear directional coupler (4).

Recently it has been shown that it is possible to obtained a nonlinear phase shift by employing the cascaded $\chi^{(2)}$ nonlinearity (5) where the second order nonlinear is employed with a nonzero phase matching condition. Theory of a so-called "push-pull" all-optical switch employing the cascaded second order effect is presented (6).

In this paper the ultrafast all-optical switching in semiconductor waveguides is reviewed for both second and third order optical nonlinearities.

(1)Sheik-Bahae,M.,Hutchings, D.C., Hagan, D. J.and Van Stryland,E. W., 1991 "Dispersion of bound electronic nonlinear refraction in solids" *IEEE J. of Quantum Elect*. QE-27 1296-1309.
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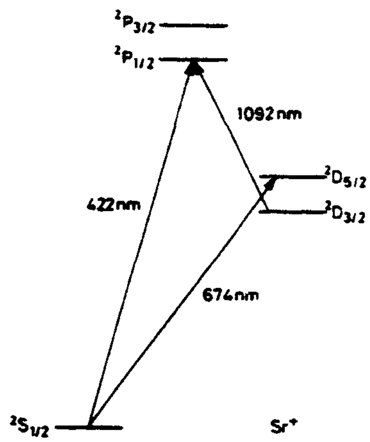

Figure 1: Partial term scheme of Sr^+ showing the transitions necessary to cool and probe trapped ions

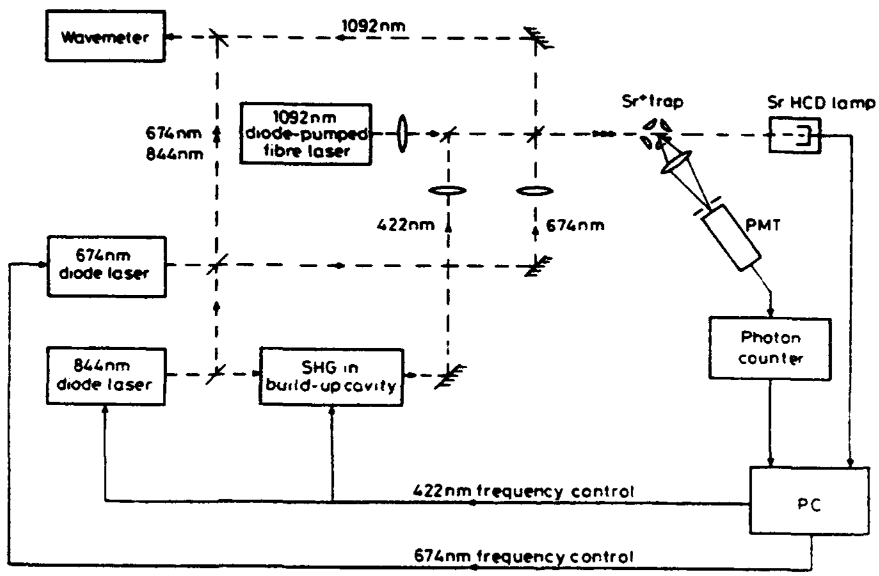

Figure 2: Schematic of the all solid state laser system for cooling and probing trapped Sr^+

OBSERVATIONS ON A SINGLE TRAPPED STRONTIUM ION USING AN ALL SOLID STATE SYSTEM OF LASERS

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Narrow transitions in various laser-cooled ions confined within a Paul (rf) trap are being considered as potential optical frequency standards. At the National Physical Laboratory (NPL), transitions in Sr^+ and Yb^+ are currently being studied. A major advantage of Sr^+ is that it can be both cooled and probed with an all solid-state system of lasers. A partial term scheme for Sr^+ is shown in figure 1. Cooling is effected with laser radiation at 422 nm and 1092 nm. The potential optical frequency standard is the $^2S_{1/2}$ - $^2D_{5/2}$ transition at 674 nm, with a theoretical linewidth of 0.4 Hz. A schematic of the overall system is shown in figure 2. The radiation at 422 nm is generated by frequency doubling the output from a high power single mode laser diode at 844 nm. Light at 1092 nm, required to drive ions in the metastable $^2D_{3/2}$ state back into the cooling cycle, is generated by a diode-laser-pumped Nd^{3+}-doped fibre laser. Finally, the probe radiation at 674 nm is generated directly by a AlGaInP single mode diode, narrowed by resonant optical feedback.

The lasers have been used to cool and probe single trapped Sr^+ ions. Scanning the cooling laser over the $^2S_{1/2}$ - $^2P_{1/2}$ transition demonstrates cooling to temperatures of less than 1 K. When the single ion is irradiated with 674 nm light, quantum jumps in the detected fluorescence from the 422 nm cooling transition have also been observed. The $^2D_{5/2}$ metastable state lifetime has been determined from the mean time the ion remains in a non-fluorescing condition while it is "shelved" in the metastable state.

The laser at 674 nm has also been scanned over the $^2D_{5/2}$ transition to produce a profile from the quantum jump data. This requires the lasers at 422 nm and 674 nm to be alternately switched using acousto-optic modulators in order to prevent broadening of the 674 nm transition by the 422 nm laser, since the transitions share a common ground state. The observed linewidth depends upon the amplitude of the micro-motion in the rf trap, the laser linewidth and the ambient magnetic field. Results of studies of both the effect of the micro-motion and magnetic field will be presented. Work on reduction of the 674 nm diode laser linewidth will also be described.

FREQUENCY METROLOGY USING TI:SAPPHIRE LASERS

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Recent work in the field of optical frequency metrology has both highlighted the possibilities for measurement of optical frequencies and shown the limitations of present standards[1]. We are working on a scheme to provide a series of visible and near infrared frequency standards which can be directly phase-locked to a well known infrared standard. We intend to produce a comb of frequencies at integer harmonics of the methane-stabilised helium-neon (HeNe) laser at f_0= 88 THz (3.39 μm).

A single Ti:sapphire (TIS) laser can be used to simultaneously produce three integer harmonics of the HeNe. The TIS laser is run at the fourth harmonic of the HeNe, at a wavelength of around 848 nm. It is phase-locked to a HeNe by beating the frequency doubled output of the HeNe with radiation at half the frequency of the TIS laser output. This subharmonic of the TIS laser is created by pumping a doubly degenerate optical parametric oscillator (OPO) which will give an output at 1.70 μm. The 1.70 μm output from a frequency doubled HeNe will then be mixed on a fast photodiode with the output from the OPO. The resultant beat note can be used to phase-lock the TIS laser to the HeNe. If part of the output from the TIS laser at 848 nm is frequency doubled, it produces light at 424 nm, the eight harmonic of the HeNe, which, again, is phased-locked to the HeNe.

Other harmonics of the HeNe can be produced by non-linear mixing of different sources. For example, light from a laser at 678 nm (the fifth harmonic of the HeNe), mixed with part of the output from the TIS laser at 848 nm in a non-linear crystal, can give radiation at 3.39 μm, the frequency of which can be compared directly with a methane stabilised HeNe. In this way the phase-locked fifth harmonic of the HeNe frequency can be produced. By frequency doubling this output we can then generate the tenth harmonic of the HeNe frequency.

One can also consider producing tuneable standards by utilising the tuneablity of carbon dioxide lasers. The primary infrared frequency f_0 would be generated by sum frequency or harmonic generation of carbon dioxide lasers, rather than using a fixed frequency device like the methane-stabilised HeNe. This could provide broad coverage and allow direct frequency measurement over much of the near infrared and visible regions.

Progress on this work will be reported at the meeting.

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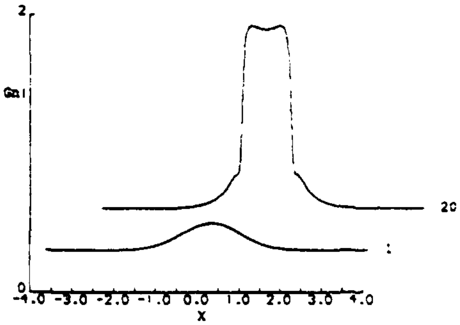

Figure 1: The beam output profiles after the 1st and 20th passes in the resonator.

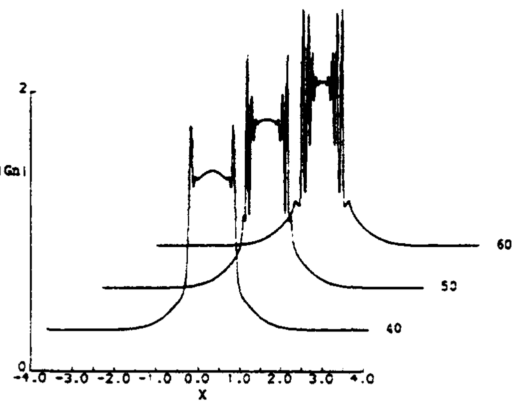

Figure 2: The initiation of the spatial ring structures after the initial transient.

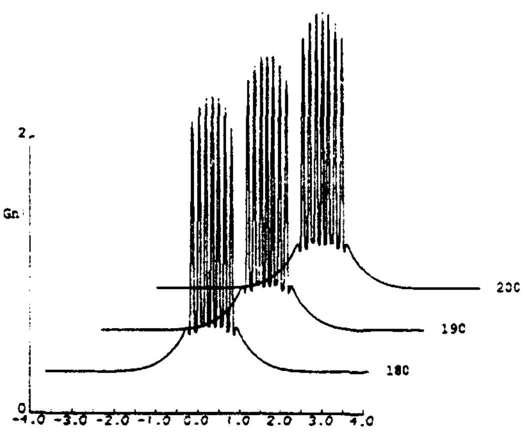

Figure 3: The asymptotic state .

Study of transverse effects in optical bistable ring resonators using the Finite Element Method

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A simulation of the transverse behaviour of a laser beam propagating through a bistable optical ring cavity has been performed using a finite-element/finite-difference beam propagation algorithm. Agreement with established results has been shown, using an inherently versatile numerical technique offering a high level of efficiency.

Summary: The numerical simulation of optical bistability in ring resonators has been performed mostly by using the fast-Fourrier transform beam propagation method[1]. However, as pointed out in [2], the fast-Fourier transform is not so well adapted for cylindrical symmetry, which one takes advantage of, when modelling Gaussian beams(the fundamental mode profile for most lasers) as the fast-Hankel-transform method ,which involves longer computing time[2] and the finite-difference method, which becomes more difficult to program when nonuniform meshes are used. By contrast the Finite Element Method has for the past decade proved to be a very efficient and versatile method in linear and nonlinear optics for modal analysis[3], with its recent extension to analyse evolutionary problems in optics[4-6]. In this paper the recentlty developed finite-element/finite-difference beam propagation algorithm[4] has been extended to study the transverse effects in a nonlinear ring resonator, taking advantage of the splitting technique[5,6].
By confining the simulation to one transverse dimension, the behaviour of a Gaussian input pulse through the resonator, has been traced. Parameters used to generate the following figures are p=2,F=200,kl=0.4rad, a_p=0.194,R=0.9[7]. Fig. 1 shows the initial transverse profile on the first resonator pass and the switched-on beam profile after the 20th pass. The initiation of the transverse spatial rings at the sharp edges of the switched-on beam, after the initial transient, are shown in Fig. 2 (n=40,50 and 60), while the asymptotic state, which had developed by the 200th pass with 7 solitary waves(solitons) for the given parameters, are shown in Fig. 3. The behaviour shown in the figures agrees well with that obtained by Moloney[7]. A useful numerical simulation technique to study transverse effects in optical bistable resonators has been developed and presented. Preliminary results for the one dimensional simulations agree well with the well established results of Moloney[7] who applied the fast-Fourier transform technique. This method presented here, with its inherent versatility will be a useful numerical technique for the analysis of optical bistability in interferometers and Fabry-Perot resonators. The method can easily be extended to two transverse dimensional and counterpropagation problems.

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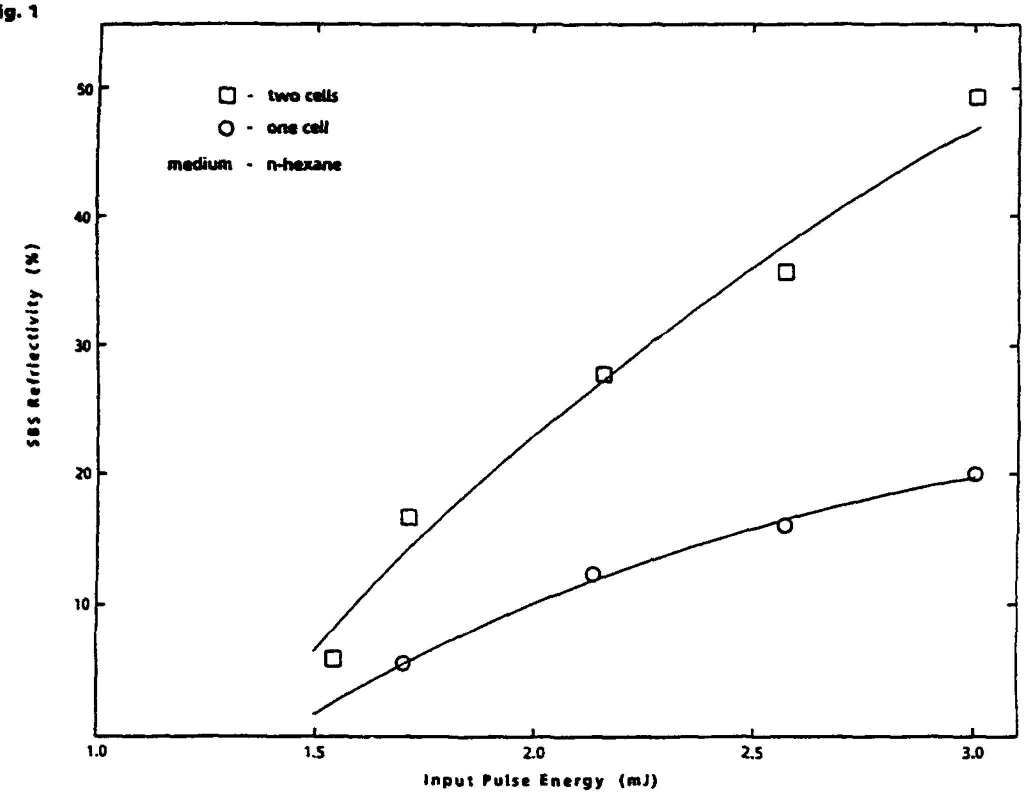
Fig. 1


□ - two cells
○ - one cell
medium - n-hexane
SBS Reflectivity (%)
50
40
30
20
10
1.0
1.5
2.0
2.5
3.0
Input Pulse Energy (mJ)

PHASE CONJUGATION OF COPPER VAPOUR LASER RADIATION USING STIMULATED BRILLOUIN SCATTERING

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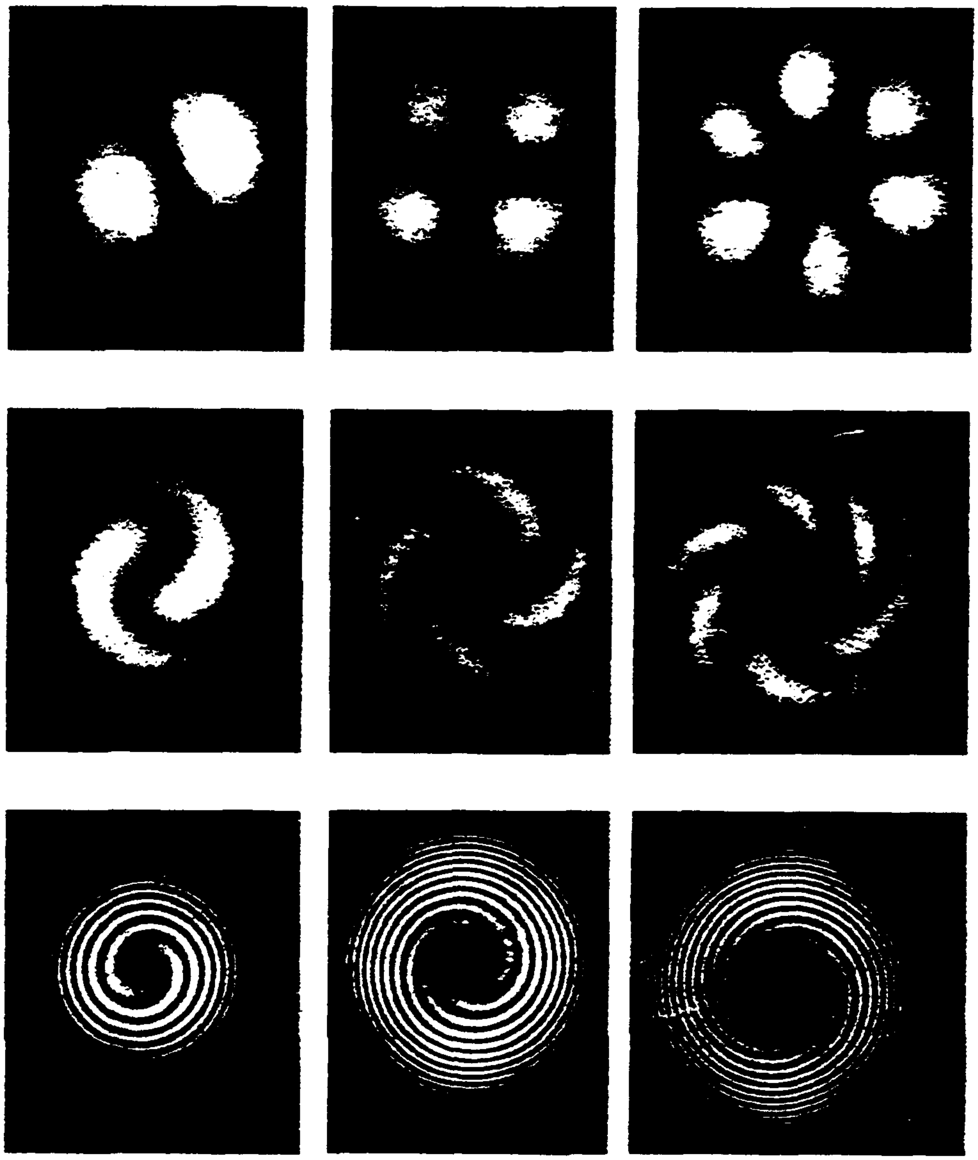
Stimulated Brillouin Scattering (SBS) of copper vapour laser (CVL) radiation has been demonstrated for the first time at multi-kilohertz repetition rates. Efficient SBS reflectivity has been achieved with a movement of the SBS medium between laser pulses of much less than the active region diameter (ie a clearing ratio <<1). Multiple cell SBS reflectors have been used to improve the reflectivity, (figure 1) and values of 70% have been achieved from 3mJ, 50ns input pulses. The influence of CVL pulse intensity, average power, beam quality and SBS medium purity on the reflectivity, phase conjugate fidelity and shot to shot stability will be presented. Some beneficial cumulative effects have been observed. The effects of SBS medium purity, which is critical to high repetition-rate operation, will be described.

By selection of SBS media and corresponding Stokes shift, the SBS conjugated signal has been shown to be capable of re-traversing a CVL amplifier during the period after laser emission, which is characterised by strong optical absorption of laser wavelength. Aberrations caused by the CVL windows are faithfully corrected.

The implications of the technique for improving CVL beam quality will be discussed.

Fig. 1: Photographs of experimental 'spiral' interference patterns. These are formed by superimposing two helical beams of opposite handedness. Patterns are displayed for modes of order 1, 2 and 3. In each case, the upper picture represents the case when the beams have equal curvature; the curvature becomes increasingly different for the lower pictures.



PURE HELICAL LASER MODES

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A well-known higher order transverse mode in many lasers is the so-called "doughnut" mode (TEM_{01}*); this has cylindrical symmetry and a dark "null" at its centre. It is less well known that a pure (single-frequency) doughnut has the property of a helical co-phasal surface (wavefront). The phase discontinuity that must occur at the dark centre leads to striking two-beam interference patterns.

We report the operation of an argon ion laser in pure doughnut modes of order $m = 1$, 2 and 3. Each mode is selected by placing an aperture and a circular absorber inside the cavity close to the axis of the laser beam. The size of these components determines the mode order. The optical spectrum and the beat frequency spectrum of the laser beam are monitored to ensure that the laser is running on a single frequency. The laser remains *linearly* polarized throughout all the experiments.

The helical character of the wavefront is clearly revealed by the interference patterns formed when the beam intersects its own mirror image on a screen at a small angle. This gives a forking interference pattern, with two, four or six extra prongs on one side of the pattern for modes of order 1, 2 or 3 respectively. The extra dark fringes come about because the wavefronts of the two opposite-handed helices intersect at different angles on either side of the pattern. Alternatively, fringe patterns can be obtained with two beams of different curvature, giving a spiral pattern (Fig. 1). The degree of curvature determines the "tightness" of the spiral, and the mode order defines the number of spirals in the pattern. It is straightforward to derive the theoretical form of these patterns, and these show excellent agreement with the experimental results of Fig. 1.

The results confirm that the wavefront of the TEM_{01}* mode consists of a simple helix of pitch λ (sometimes referred to as an an *optical vortex* with a *charge* of one). However, the second-order mode wavefront must consist of two helices, each of pitch 2λ, displaced longitudinally by λ. Likewise, the $m = 3$ mode wavefront is a triple or *three-start* helix.

OPTICAL TRANSMISSION PROPERTIES OF SINGLE CRYSTAL FIBRES

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Fibres of single crystals can be grown by the Miniature Laser Heated Pedestal Growth Technique [1]. A carbon dioxide laser is focused on the tip of a source rod of the material of interest to create a small molten region, into which a seed crystal is dipped and extracted slowly to produce a crystal in fibre form. In this way doped and undoped fibres may be obtained for applications in lasers, nonlinear optics and sensors.

Diameters and lengths are usually of ~ 50-500 microns and a few cms respectively, and hence their optical properties can fall midway between those of traditional optical fibres and rods. To be able to assess the operation of a fibre based device requires a knowledge of the light path, such that the intensity profile, phase, polarisation and pulse duration of light that has either traversed or been generated within it can be predicted.

Detailed experiments have shown that the output spot from a short length of crystal fibre is dominated by Fresnel diffraction of the axial light at the exit aperture, superimposed on a weak interference pattern caused by the off-axis light being totally internally reflected from the fibre wall. In addition, since most crystals are anisotropic, both the axial and off-axis paths are usually birefringent and thus the state of polarisation of the light will change as it propagates. Experimental techniques include diode array scanning of the spot, comparison with equivalent patterns from capillary tubes and pinholes and sum frequency cross-correlation measurements of transmitted pulses from a mode locked cw laser.

In this paper, the results of these investigations will be presented and the optical properties of single crystal fibres discussed in general.

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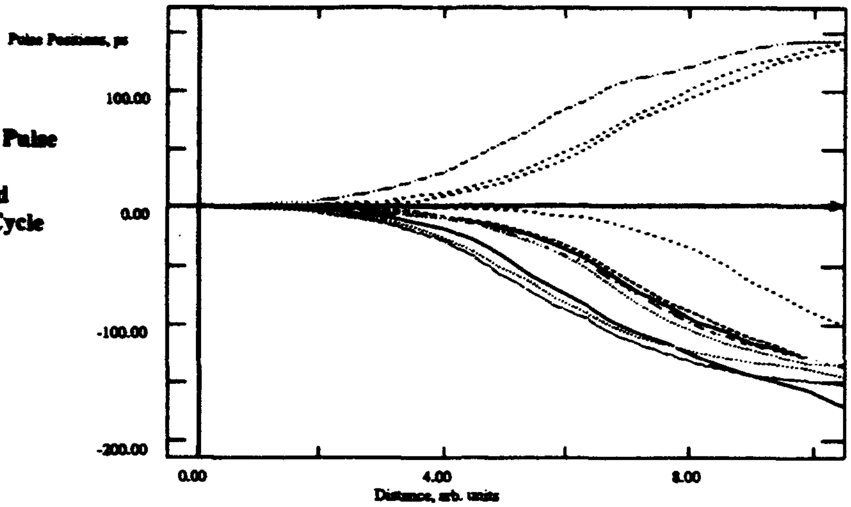
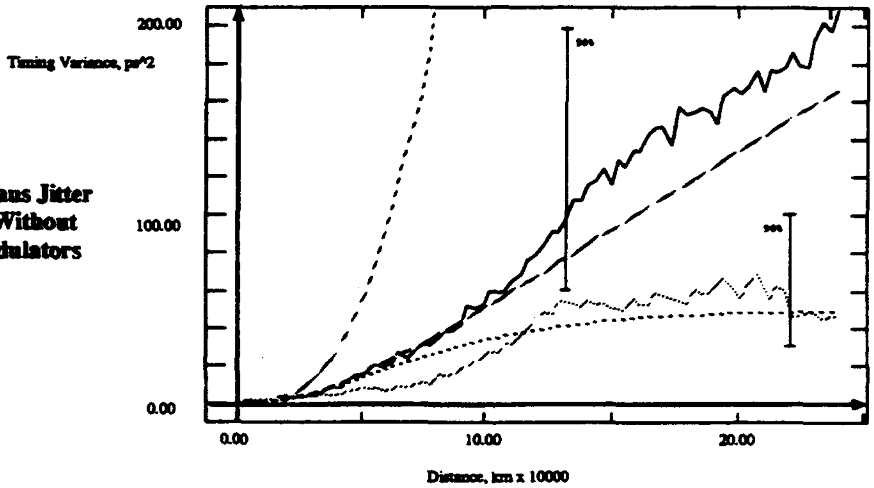
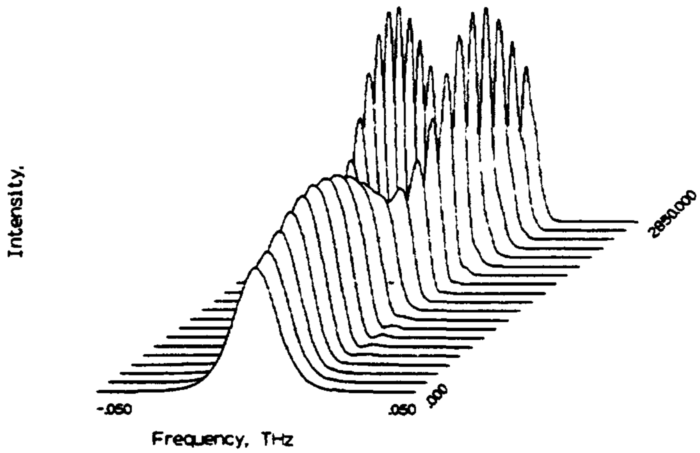
1. Evolution of Pulse Positions on Downchirped Modulator Cycle



2. Gordon-Haus Jitter With and Without Phase Modulators



3. Soliton-Continuum Coupling on Downchirped Extrema of Modulator Cycle



SOLITON DYNAMICS IN THE PRESENCE OF PHASE MODULATORS

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There have been many recent demonstrations of soliton behaviour in mode-locked fibre lasers[1,2]. This work investigates analytically and numerically the evolution of a soliton's parameters under the influence of phase modulation, relating the results to experimental demonstrations of FM mode-locked fibre lasers[3]. The topic also has relevance to optical fibre communications in that electro-optic amplitude modulators have been shown to reduce the effects of Gordon-Haus timing jitter[4,5]. The equivalent results for phase modulation are presented here.

Using the techniques of soliton perturbation theory, and numerical integration of the Nonlinear Schrodinger equation, the following results are demonstrated:

- Solitons at the down-chirped extrema of the phase modulator cycle are unstable with respect to any small change in their temporal position or velocity. This is in sharp contrast to the Kuizenga-Siegman theory[6] valid in the absence of Kerr effect. Figure 1 shows the evolution of the positions of an ensemble of solitons, initially situated at this peak of the modulator, due to the effect of a.s.e. noise.

- The up-chirped extrema of the modulation cycle, together with a bandwidth restriction, will limit the growth of Gordon-Haus jitter to a finite value. In this respect it is considerably more effective than an amplitude modulator. The timing variances of 20ps FWHM solitons in a transmission system are shown in figure 2 both with and without phase modulators.

- The down-chirped modulator position is also more susceptible to coupling between the soliton and continuum (dispersive) radiation modes. This is due to cancellation of the soliton's natural phase by the modulator imposed phase shifts, allowing resonances to occur in the wings of the pulse. An example of this behaviour is shown in figure 3.

In conclusion, the design of actively mode-locked fibre lasers should employ amplitude rather than phase modulation techniques to avoid the problems associated with the down-chirped modulator position. Phase modulation may still prove to be a useful technique in soliton transmission systems, however, where the pulses may be *a priori* chosen to occupy the up-chirped position.

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ERBIUM-DOPED FIBRE LASER WITH FREQUENCY-SHIFTED FEEDBACK

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We report the operation of an erbium-doped fibre laser incorporating frequency-shifted feedback (FSF) to generate a continuous modeless frequency spectrum. The laser cavity consists of approximately 8m of fibre butted at one end to a highly reflecting mirror in the 1.5um region and end pumped through this mirror with a Ti:Sapphire laser operating at 980nm. Light emerging from the other end of the fibre is passed through an intracavity acousto-optic modulator (AOM) orientated at the Bragg angle to frequency upshift the fibre laser field in the first order diffracted beam. Retro-reflection of this beam with a second highly reflecting mirror provides the feedback for laser oscillation. Output coupling is achieved via the zeroth order diffracted beam. The AOM induces a discrete frequency shift upon each transit of the laser field, such that the total round trip shift is twice the AOM frequency. The frequency shift prevents the build up of longitudinal modes that otherwise arise from constructive interference of fields of the same frequency and phase and thus generates a continuous, modeless frequency spectrum. Further, when the AOM frequency is set equal to the cavity round trip frequency, pulses are observed in the output with a period corresponding to twice the modulator frequency. With the AOM set at 80.6 MHz we observed pulses spaced by 6.2 ns, corresponding to a total shift of 161.3 MHz.

The temporal behaviour of the FSF laser is dependent on the cavity losses, which can be varied by changing the modulator RF power to alter its diffraction efficiency. This then determines the total amount of feedback into the fibre. Three distinct operating regimes have been identified with this technique:

Region I: for very low feedback levels (up to about 0.6%) the output is CW (with the 6.2 ns pulse ripple on top) with a spectral width of about 100 GHz symmetrical about a peak wavelength of 1532.0 nm. The linewidth under non-shifted feedback conditions is 40 GHz.

Region II: increasing the feedback between 0.6% and 2.5% switches the output to a train of driven relaxation oscillations (DRO) containing within them the 6.2 ns pulses as before. The spectral width is now about 200 GHz, with peak wavelength 1532.0 nm

Region III: increasing the feedback further terminates the DRO operation and generates a third regime where the output consists of pulses spaced by 62 ns, such that the power contained in ten of the 6.2 ns pulses is now concentrated within one 62 ns pulse. The spectrum is distorted such that the long wavelength side is enhanced and the peak is shifted to 1532.6 nm with a width of about 80 GHz.

The FSF laser power slope efficiency for maximum feedback is 15% with a maximum output power of 20 mW and a threshold of 10.5 mW launched. The generation of a broad RF spectrum when heterodyning the FSF output with a single frequency DFB laser at 1532 nm confirms the lack of a longitudinal mode structure. An FSF laser operating in the 1.5 micron region should find applications where a broadband spectrum is required, e.g., for optical gyroscopes, and injection-seeding the FSF laser with a single frequency source is expected to produce a comb of frequencies separated by twice the AOM frequency with applications in spectroscopy for determining the spacing between an unknown optical frequency and a reference frequency.

THULIUM-DOPED LEAD GERMANATE FIBRE LASERS

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To date research on optical fibre lasers and amplifiers has mainly concentrated on two classes of host glass, silicates and fluorozirconates. In this paper we present results obtained from a new glass, based on lead germanate. This glass has been chosen to answer a need for a host having a maximum phonon energy intermediate between that of silica and fluorozirconate glass. The specific glass composition was also developed to be suitable for fibre fabrication. We report results of lasing on two transitions in thulium-doped lead germanate fibre. Recently this new glass has also been shown to be compatible with ion implantation techniques to produce planar waveguide lasers.

One of the disadvantages of silica as a glass fibre laser host is that its high maximum phonon energy leads to rapid non-radiative decay between levels of dopant ions, so that these ions have relatively few metastable levels, thus limiting the number of possible laser transitions. Fluorozirconates, such as ZBLAN, with a much lower phonon energy, allow many more metastable levels. On the other hand, since non-radiative decay processes can in some circumstances be of value in channelling excitation to the upper laser level, the need can arise for a specific, optimum value of phonon energy. The 1.9μm transition in Tm^{3+}, pumped at 790nm, is such a case in point where a phonon energy intermediate between that of silica and ZBLAN is called for and it was to optimise the performance of this laser that we developed this new glass. It should also be added that ZBLAN is difficult to fabricate, fragile and hygroscopic. The new lead germanate fibre shows good mechanical properties and can be fabricated by the standard rod-in-tube method.

We will present results for lasing performance in a thulium-doped lead germanate fibre. The observed threshold for the 1.9μm transition, 3.6mW using a diode pump, is the lowest reported for this transition, indicating that the deliberate choice of host phonon energy can be beneficial. This transition is of interest for LIDAR, sensors and medical applications so the lead germanate system, with further optimisation, could play an important role in these areas. Another wavelength of interest is at 810nm which falls within the first telecommunications window. We report lasing at this wavelength in a Tm-doped lead germanate fibre resonantly pumped at 790nm. The possibility of high gain on this transition has been confirmed with the observation of lasing directly off the uncoated cleaved ends of the fibre.

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NARROW LINEWIDTH COUPLED CAVITY ALL FIBRE GRATINGS LASERS

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Narrow linewidth, single and dual frequency lasers are of considerable interest for various applications in fibre optics instruments, telecommunications systems and sensors. Erbium-doped fibre lasers using fibre grating reflectors are attractive for such applications. Monolithic short cavity highly-stable single frequency lasers based on the use of gratings in a linear cavity have recently been reported. In this paper we demonstrate integrated erbium-doped fibre coupled cavity lasers using fibre gratings. The use of multi-cavity laser configurations permitted us to achieve robust single-frequency laser operation as well as dual frequency generation with high stability of wavelength separation between the two laser modes.

A single-frequency fibre grating laser with external fibre grating etalon is reported. The laser had a length of 6.5 cm and consisted of a 5 cm erbium-doped fibre grating laser cavity and a 1.5 cm external passive fibre grating resonator. The laser was pumped at 980nm and operated at 1555 nm. The laser linewidth was less or equal to 10 MHz which was limited by the instrument resolution. The operational wavelength could be continuously tuned by temperature over the range of ~1nm. The implementation of the external etalon improved considerably the spectral selectivity of the laser cavity providing robust single-frequency operation.

A dual frequency coupled-cavity laser is reported. To achieve dual frequency operation, the laser was configured by two laser cavities. Each cavity consisted of two grating reflectors spliced to an erbium doped fibre. The difference between the centre wavelengths of two resonators was about 0.5 nm. Such laser configuration provided coupling between two laser cavities, and hence coupling between laser modes. As a result, high stability of the frequency separation between two laser modes was achieved. The linewidths of the two frequencies were less or equal to 10 MHz. The frequency separation was about 56 GHz, and its deviation was within 10 MHz with proper stabilisation of the laser temperature and pump power.

HIGH REPETITION RATE FEMTOSECOND SOLITON GENERATION FROM AN YTTERBIUM-ERBIUM FIBRE LASER

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Erbium-doped fibre lasers have recently been the subject of much investigation as potential sources of ultrashort femtosecond pulses at 1.55 μm, the minimum loss wavelength of silica fibre. Fibre doped with both Ytterbium and Erbium has the advantage over solely Erbium-doped fibre that it has a broad absorption band. This allows it to be pumped both by Neodymium-YAG lasers at 1.064 μm and also by cheap and readily available AlGaAs semiconductor lasers around 850 nm, making it capable of higher potential signal powers than Erbium-doped fibre. The fibre used in this experiment, for example, was capable of generating more than 500 mW c.w. at 1.55 μm.

A "Figure of Eight" cavity arrangement similar to that used in Erbium-doped fibre lasers was built and pumped with a Nd-YAG laser. After minimising both the overall dispersion in the cavity and the cavity length this produced pulses as short as 250 fs with a mode-locked threshold of only 52 mW of pump power and a maximum output power of 22.7 mW for a launched pump power of 1.4W.

This laser displayed an unusual temporal output pattern which consisted of short trains of identical femtosecond pulses with an even spacing of a few picoseconds. The number of pulses in the train could be continuously adjusted from 1 to a maximum of ~20 by adjusting the launched pump power and polarisation controllers. In this mode of operation pulse durations were typically ~800 fs and repetition rates in the range of ~150-350 GHz were observed. This behaviour (which was not associated with Q-switching in the cavity) was most likely related to the inherent birefringence in the fibre system. The laser also displayed the typical temporal output pattern of passively mode-locked fibre lasers without repetition rate control. This consisted of bunches of randomly spaced pulses periodic at the round trip time of the cavity with the number of pulses present being proportional to the pump power.

THEORY OF FM MODE-LOCKED FIBRE LASERS

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We present results obtained from a computer model representing a type of FM mode-locked fibre laser demonstrated by Greer and Smith [1] at British Telecom. In this ring laser system, cross-phase modulation (XPM) is imposed by an injected pulse that co-propagates with the main pulse for a section of the fibre loop. The process is complicated by the fact that the two pulses have slightly different group velocities (the "walk-off" effect).

We have identified a primary pulse formation mechanism in a computer model of this system in which self-phase modulation (SPM) and group velocity dispersion (GVD) are neglected. The model is a development of the one used by Catherall and New [2] in their study of noise in synchronously pumped dye lasers. An element is inserted into the model to simulate the XPM effect. Results are presented showing the sensitive dependence of the pulse profiles on the detuning of the modulation frequency from the natural frequency of the cavity.

The real laser cavity contains many kilometres of optical fibre and inclusion of SPM and GVD is therefore essential. In this research, the Nonlinear Schrödinger Equation is considered as the governing equation for a pulse propagating inside the fibre. The computer model involves two linked loops, one simulates pulse propagation in the fibre and the other simulates the gain, spectral filtering and the detuning. It should be noted that a computer model of a passively mode-locked laser with SPM and GVD has been successfully developed by Avramopoulos et al [3] in the past.

A wide range of computer results will be presented for a range of parameter values. These will be compared with recent experimental results from the British Telecom.

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MULTIPHONON RELAXATION IN LOW PHONON-ENERGY Pr^{+3} GLASSES

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Recently there has been a great deal of interest in optical fibre amplifiers and lasers operating in the 1.3 μm wavelength telecommunications window; for this application, Pr^{+3}-doped low phonon-energy glasses have attracted a great deal of attention. In these glasses the lifetime of the metastable level is dominated by non-radiative relaxations, of which the two most important processes are multiphonon decay and concentration quenching. The doping levels are thus limited by the need to avoid the latter; while the former effectively determines the lifetime in lightly-doped glasses. The aim of this work has been to investigate the crucial parameters which control the multiphonon decay rate in low phonon-energy glasses and their dependence on glass constituents.

The multiphonon decay rate is described by the Pekarian function[1]:

$$W_{MP} = W_0 \ (n+1)^p \ e^{-g} \ \frac{g^p}{p!}$$

where $n = (e^{\hbar\omega/kT} - 1)^{-1}$ is the phonon occupation number,
$p = \Delta E/\hbar\omega$ is the number of phonons mediating the decay process,
g is the electron-phonon coupling constant,
ΔE is the energy gap,
$\hbar\omega$ is the individual phonon energy.

It is thus evident that the rate increases with both the coupling constant g and the phonon energy $\hbar\omega$: therefore in order to increase the lifetime one or both must be reduced.

In general, the phonon energy can be reduced by substituting heavier ions for the appropriate glass constituents, in accordance with the Szigeti[2] equation

$$\omega \sim (K/M)^{1/2}$$

where K is the bond strength and M is the reduced mass. However, since the phonon energy and the coupling constant are independent parameters, a composition which decreases $\hbar\omega$ may also coincidentally increase g, thus cancelling any beneficial effect on the lifetime.

In this work we measure the two parameters $\hbar\omega$ and g, demonstrate their variation with composition, and use the obtained values to calculate the expected multiphonon decay rate. The predicted rate is then compared with the observed fluorescence lifetime and with predictions achieved by other models. The method is used to assess low phonon-energy glasses for their suitability as hosts for Pr^{+} in applications at 1.3 μm wavelength.

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OPERATION OF YTTERBIUM-DOPED SILICA FIBRE LASERS AT SPECIFIC WAVELENGTHS USING FIBRE GRATINGS

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Yb-doped fibre lasers have been previously reported as versatile, efficient laser sources in the 1 μm spectral region. The very broad Stark splitting of Yb energy levels in silica results in wide pump (830 - 1064 nm) and emission (975 - 1160 nm) bands [1,2]. The emission band includes a number of wavelengths of interest for specific uses; examples include 1020 nm, the optimum pump wavelength for the Pr:ZBLAN amplifier and upconversion laser [3], and 1128 nm, which has been utilised to pump a Tm:ZBLAN upconversion laser [2].

An attractive approach to achieve efficient laser operation at any wavelength within the emission band is to incorporate fibre gratings into the laser cavity [4]. In this work we report the performance of Yb-doped silica lasers operating at 1020 nm and 1128 nm. Gratings having reflectivities up to 99% at 1020 nm and 1128 nm were fabricated in silica fibre using a technique described elsewhere [5]. These gratings were fusion-spliced to silica fibre doped with 700 ppm of Yb. Laser performance has been compared to predictions from a small-signal computer model which predicts laser thresholds, and the amount of selectivity required to suppress oscillation at free-running wavelengths.

Laser action occurred at 1020 nm when pumped at 840 nm using a Titanium Sapphire laser. For a 10 m length of fibre, gratings having reflectivities of 95% and 30% at 1020 nm were spliced to the input and output ends of the Yb:SiO_2 respectively to suppress the free-running wavelength of 1050 nm. The output consisted of 260 mW at 1020 nm, and 50 mW of unabsorbed pump light for 660 mW launched pump. Angle-polishing of the fibre input end was found to be beneficial in suppressing the free-running wavelength. The relative output at the two wavelengths could be varied by changing the length of doped fibre.

Laser action has also been demonstrated at 1128 nm in Yb:SiO_2, pumped at 1064 nm by a pulsed NdYAG laser (5ms pulse duration). Due to very weak absorption of the pump, a fibre length of ~100 m was used, and the laser cavity consisted of a mirror (99% reflectivity at 1128 nm) butted to the input end of the doped fibre and a grating (50% reflectivity at 1128 nm) spliced at the output end. This configuration suppressed the free-running wavelength (1115 nm) and constrained laser oscillation to 1128 nm. 1.4 W peak power was achieved for an incident power of 10.6 W, and this output was then employed to obtain upconversion laser action at 480 nm from a Tm-doped ZBLAN fibre laser.

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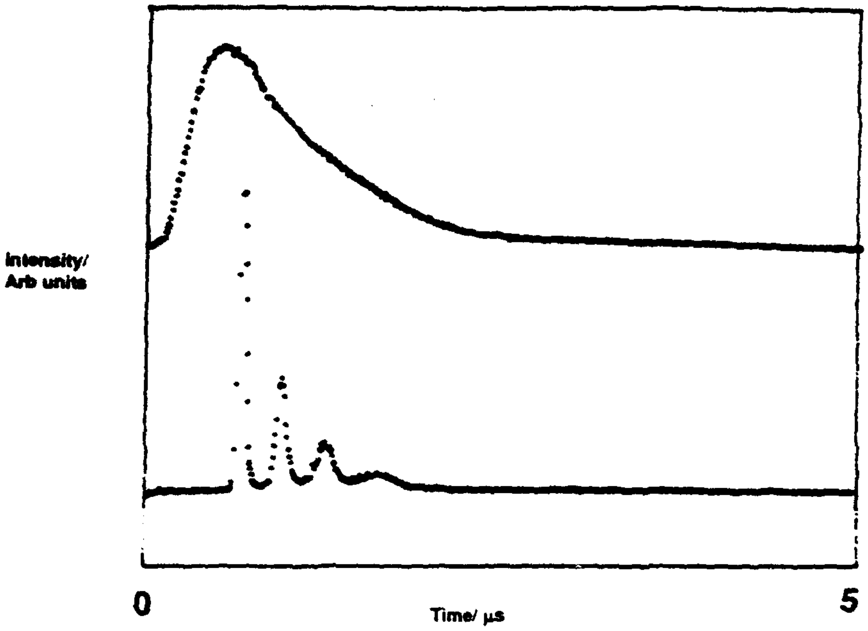

Fig. 1: Oscillogram of 10 accumulated xenon ion (top) and titanium sapphire (bottom) output pulses.

OUTPUT CHARACTERISTICS OF A XENON-ION LASER PUMPED Ti:SAPPHIRE LASER.

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The strong green laser lines of triply ionised xenon have been utilised in the longitudinal pumping of a titanium sapphire crystal. The xenon-ion laser provides five lines, in a non-selective cavity, near to the peak of the absorption band of titanium sapphire, with a pulsewidth of ~1.5μs, which is relatively close to the upper state lifetime of $Ti:Al_2O_3$. These characteristics, and repeatable pulse shapes and good quality TEM_{00} spots, lend themselves to the efficient pumping of the titanium sapphire crystal. Coupled with the relatively inexpensive technology required for its construction, the xenon-ion laser provides an attractive pump source for a titanium sapphire laser.

The experimental performance of the xenon-ion pumped titanium sapphire laser system, incorporating a Russian, 10mm AR coated, 0.1wt % Ti doped crystal, is presented for a variety of operating conditions. In a confocal non-selective cavity the laser output was centred at 758nm with a total range of 22nm. Spectral structure within this range, similar to previous work [1], is demonstrated with the use of a diode array placed at the exit aperture of a grating spectrometer. The spectral range and the temporal characteristics are dependent on the pumping power. Relaxation oscillations similar to those observed in pulsed dye laser pumping [2,3] are evident for pumping well above threshold, fig. 1. Tuning characteristics are presented for various tuning regimes. Slope efficiencies are presented and compared with those obtained with other pumping lasers.

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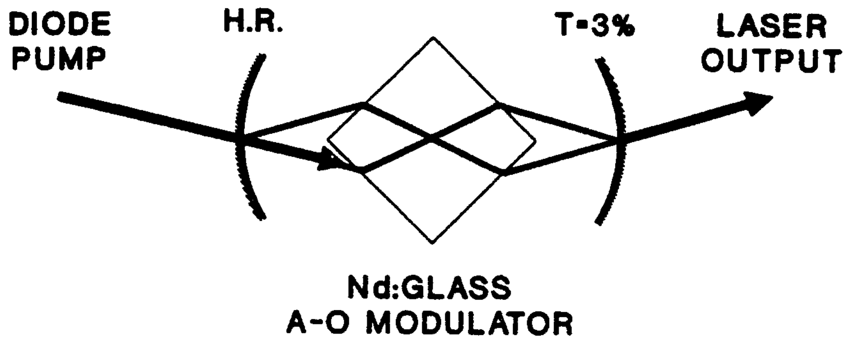

Fig. 1. Diode-pumped Nd-doped phosphate glass ring laser.

UNIDIRECTIONAL Nd-DOPED PHOSPHATE GLASS RING LASER USING THE ACOUSTO-OPTIC EFFECT IN THE LASER MEDIUM

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Enforcing unidirectional operation of a ring laser using an intracavity travelling-wave acousto-optic (A-O) modulator can be an effective way to achieve both efficient and reliable single frequency operation [1]. Recently, it has been shown that there are two distinct mechanisms [2],[3],[4] which are responsible for the non-reciprocal behaviour of a travelling-wave A-O modulator, and in both cases it has been demonstrated that a sufficient value of loss difference to ensure unidirectional operation can be achieved at very low r.f. powers. This fact suggests that many laser materials, not previously noted as having a high enough figure of merit for many acousto-optic applications, may nevertheless prove to have a more than adequate figure of merit for A-O unidirectional devices.

In this paper we describe a useful extension of the acousto-optic technique for enforcing unidirectional operation of a ring laser in which the laser medium is also the A-O modulator. The resonator design used (shown in Fig.1), is a simple three-element ring cavity which contains a Brewster-angled, travelling-wave A-O modulator, fabricated from Nd-doped phosphate glass. This was designed to operate with a r.f. drive of 250MHz and produced a maximum diffraction loss (at 1.053μm) of ~1% for an applied r.f. power of 1W. When pumped by a 1.2W, high-brightness diode, preliminary results indicated that the lasing threshold occurred at an incident pump power of approximately 230mW. The maximum output power achieved was limited by thermally-induced stress birefringence to ~85mW for a pump power of 560mW. Unidirectional and single-frequency operation were achieved by applying a low power r.f. signal (~0.008W) and aligning the modulator close to the Bragg condition.

In view of the very low values of acousto-optic figure of merit required for A-O unidirectional devices confirmed by this experiment, it is anticipated that many other laser materials will prove appropriate for this scheme of unidirectional operation. This offers the prospect of a number of very compact and stable, all-solid-state, single frequency ring lasers.

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A INVESTIGATION OF THE Q-SWITCHED Cr^{4+}:YAG LASER SYSTEM

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We have carried out an investigation of the operating conditions of a new near infra-red solid state laser. This Cr^{4+} based laser adds to the family of transition metal ion based solid state lasers.

The Cr^{4+}:YAG system is a tunable laser operating in the spectral range 1.36 - 1.52 μm. This is the broadest tuning range yet achieved for the Cr^{4+} based solid state lasers. Nevertheless, the tuning range does not cover the full luminescence spectrum indicative of lossy mechanisms such as excited state absorption.

In Q-switched operation the laser is pumped with a 5 ns Nd:YAG pulse. The resultant Cr^{4+} pulse width is 60 ns. Typical operating conditions are 40 mJ pumping to reach threshold, and an output at the peak of the Cr^{4+}-tuning range of 7.5 mJ for a pump energy of 150 mJ.

This laser exhibits some very interesting temporal dynamics as measured by the delay between the pump and output Cr^{4+} pulses as a function of both pump energy and tuning position. We are at present modelling this behaviour.

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BEAM COMBINATION BY RAMAN TECHNIQUES

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The ability of a Raman amplifier to combine the energy of a number of pump beams into a single beam can be used to extend the energy capability of pulsed laser systems. Beam combination can be particularly valuable in systems pumped by doubled Nd:YAG since a gas Raman cell can withstand higher energies than can frequency doubling crystals, and the short pulses provided by Q-switched lasers can readily produce Raman effects. Our programme addresses the combination of separate frequency doubled beams in a Raman amplifier. Energy is extracted from the amplifier by the injection of a seed beam at the Raman-shifted wavelength, generated in a separate Raman oscillator.

Preliminary results will be presented showing the combination of separate 532 nm pump beams into a single beam at 683 nm using a hydrogen Raman cell. Energy extraction data will be presented. The requirements for coherence of the pump beams will be discussed.

ORIGINAL METHOD FOR SIMULTANEOUS MEASUREMENT OF THE EMISSION LIFETIME, GAIN AND CROSS SECTION AT 1.06 AND 1.3 μm IN NEODYMIUM-DOPED OPTICAL WAVEGUIDES.

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We propose an original method for measuring the gain and the emission cross-section of a four level system in rare-earth doped optical waveguides. This method is based on a temporal analysis of the fluorescence decay occuring when the pump is switched off, after establishing a steady state with a CW pump laser. This method has two significant advantages: 1) It is not required to launch an optical signal in the waveguide; therefore adjusting the set-up is greatly simplified and the reproducibility of the results is improved. 2) The experimental set-up is the same for measuring either the metastable level lifetime or the gain, permitting the straightforward calculation of the emission cross-section.

The method has been applied to Neodymium in optical fibres; we have compared our results with those obtained by the usual low signal amplification technique, which requires to launch an optical signal into the fibre. In a silica-based Nd-doped fibre, we have measured a gain per unit of absorbed pump power of 0.23 dB/mW at 1.06 μm, in very good agreement with 0.24 dB/mW found by the usual method. The calculated cross-sections were found to be $(5.7\pm1.1)\times10^{-25}$ m^2 and $(6.4\pm1.2)\times10^{-25}$ m^2, respectively.

We have applied our method to the measurement of the gain of the gain-guided amplified spontaneous emission at 1.052 and 1.322 μm in a 1.5 mm long stochiometric $KNdP_4O_{12}$ crystal transversaly pumped at 0.8 μm by a high power semiconductor laser. The gain values were 0.06 dB/mW (maximum achieved 6.1 dB) and 0.03 dB/mW (max. achieved 3 dB) respectively. To our knowledge, it is the first report of a gain mesurement in this material, which is very interesting for compact diode-pumped IR laser sources.

The new technique allows, therefore, a rapid and simple method of gain measurement in a Neodymium-doped waveguide with a relatively good accuracy. The model involved in our technique can be directly extended to the measurement of gain and emission cross-section of any four-level atomic system in a waveguide, provided that the emission spectrum is at least "quasi homogeneously" broadened and that the lifetime of both the lower laser level and the pumped level are negligeable relatively to the metastable level lifetime.

WAVEGUIDE FLUORESCENCE SPECTRA STUDIES IN ION-IMPLANTED CR:LINBO3

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Abstract

Waveguides have been formed in Cr:LiNbO$_3$ by ion implantation at liquid nitrogen temperature. For 2 MeV He+ ions a waveguide of depth ≈ 4 μm was formed so that the c-axis of the crystal is perpendicular to the direction of propagation. The crystal environments of the Chromium ions in the guide are investigated, by *comparing fluorescence* spectra of the guide to those of the bulk, for the two polarisations. Losses in the guide are studied, with regard to the damage distribution (using refractive index profiles) and the scatter and absorption losses due to defects, before and after annealing. Suggestions are made as to the suitability of Cr:LiNbO$_3$ for laser action in the guide.

DIODE LASER PUMPED ND:YAG MINI SLAB LASER AND ITS FREQUENCY DOUBLING

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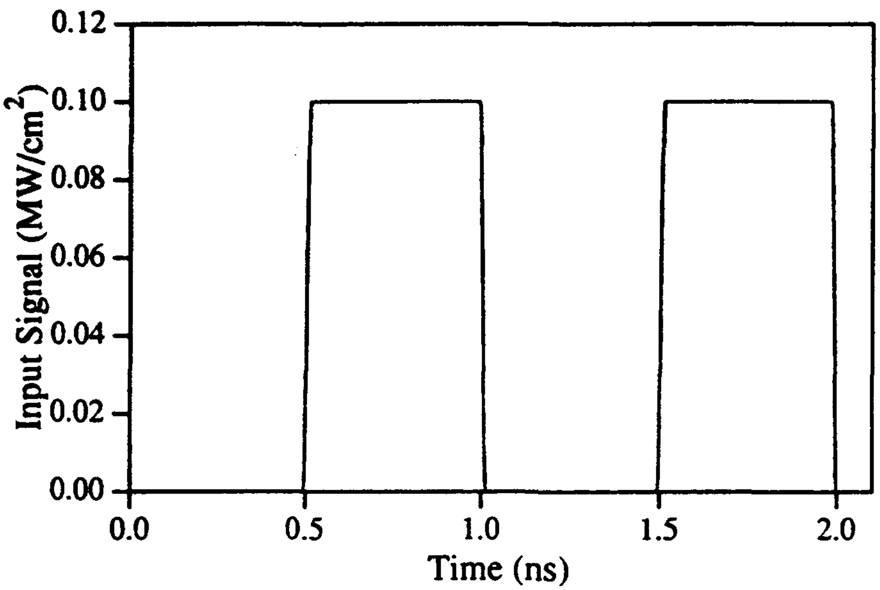
A scalable pumping scheme for high power diode laser arrays has been investigated. A CW Nd:YAG laser pumped by two 10-W diode laser bars was developed. It produced up to 3.6 W of power in a diffraction limited TEM_{00} beam. The Nd:YAG crystal used was specially cut in a slab geometry which employed two total internal reflections of the Nd:YAG laser beam. At both reflection sites a diode laser bar directly pumped the slab. A good overlap between pumped and TEM_{00} lasing volumes was maintained in this scheme. With this pumping geometry, a simple linear cavity provided a linearly polarised 3.6-W TEM_{00} output at 1.064 μm. A power stability of ± 0.5 % and beam pointing stability of < ± 10 μrad has been achieved. This highly stable output in a diffraction limited beam is highly desirable for powering optical logic arrays, or for use in powering lasers or optical parametric oscillators which demand high beam quality and stability.

A four-mirror "bow tie" type ring cavity has also been developed with the same laser head module, and 2-W of single frequency laser output was generated by employing a Faraday type unidirectional device in the laser resonator. A 20-mm long LBO crystal was used for intracavity second harmonic generation. 1 W of stable single frequency laser output at 532 nm was achieved.



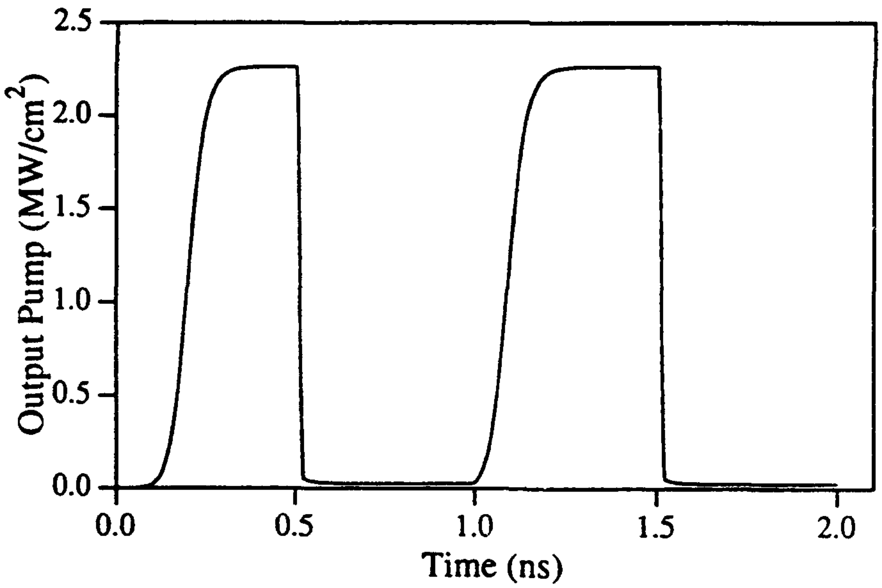


FIGURE 1. Numerical simulation of a 0.1 MW/cm^2 square wave input signal beam interacting in a dye (Rh6G) with a 15 MW/cm^2 CW input pump beam producing a switched output pump beam with a quasi square wave shape which varies from 0 to 2.4 MW/cm^2. The dye concentration is 4×10^{16} cm^{-3}.

A FAST OPTICAL SWITCH FOR HIGH-POWER RADIATION

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The operation of an ultrafast high-power optical switch is reported. A simulation of the experimental results is presented as well as an analysis of the response tieme of the device and its overall effficiency. As it is well known, laser-pumped fluorescent dyes have been widely used as tunable amplifier media of incident laser signal beams across a wide wavelength range[1,2]. However, recently it has been shown[3] that in the steady-state the transmission of the *pump* beam can be strongly controlled by the intensity of the signal beam. Based on this idea in this work we report results showing that a very fast high-power optical switch can be operated using a dye cell as switching device of a pump beam where the switching process is controlled by the signal beam. Experimental results are presented and compared with numerical simulations. Also, an estimate of the time constant of the system is obtained by neglecting the upper-level transitions in the dye medium. As it has been shown[3,4] the presence of these transitions causes a (generally small) asymmetry on the transmission and amplification of the pump and signal when the beams are copropagating or counterpropagating.

Our calculations show, in agreement with experimental observations, that the time constant of the device diminishes with the magnitude of the intensities of the pump and signal beams. Moreover, for typical experimental values of pump and signal intensity (~ 10^2 MW/cm^2) the time constant is approximately 5 psec. Figure 1 shows a numerical simulation illustrating the switching properties of the device. In this example, a 0.1 MW/cm^2 square wave input signal beam interacting in a dye (Rh6G) with a 15 MW/cm^2 CW input pump beam produces a switched output pump beam with a quasi square wave shape which varies from ~ 0 to 2.4 MW/cm^2.

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THE LINEAR AND NON-LINEAR OPTICAL PROPERTIES OF POLYDIACETYLENE THIN FILMS

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All optical switches require materials which are easily fabricated into structures which combine large third-order optical non-linearity, $\chi^{(3)}$, with low loss. Thin films of the 9-BCMU polydiacetylene possess some of the appropriate properties and using the dipping technique can be produced in either the crystalline blue phase or the less ordered red phase forms[1]. A variety of experimental techniques are employed in order to investigate the properties of 9-BCMU relevant to potential switching devices.

The linear absorption spectra reveal an absorption edge shift of ~0.3 eV between the two phases leading to the values of $\chi^{(3)}$ and the linear refractive index being dependent upon the solid state phase of the 9-BCMU films. The M-line prism-coupling technique was employed to measure the linear refractive indices. Values of 1.646 ± 0.002 at 633 nm (near resonance) and 1.5704 ± 0.002 at 1.3 μm (off resonance) were obtained for red phase films.

The third-order non-linear properties were studied in the visible region using sub-picosecond degenerate four-wave mixing and pump-probe techniques and the Maker Fringer technique is used to measure the third-harmonic at 1.907 μm. The refractive and absorptive parts of $\chi^{(3)}$ have been evaluated at wavelengths near-resonance and within the absorption tail of the materials[2]. Near-resonance values for $\mathrm{Im}\chi^{(3)}$ were found to be 7×10^{9} esu for the red phase and 5×10^{-8} esu for the blue phase, with a response time of 1.7 ± 0.1 ps. A saturated absorption effect was found near-resonance changing to an induced absorption effect on moving into the absorption tail[3].

These measurements enable the characterisation and modelling of the third-order optical non-linearity of these materials.

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Electron Emission From Selected Metal Surfaces By Multiphoton Absorption Of Nd:YAG Radiation.

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Two possible mechanisms for the ejection of electrons from a metal surface are: a) the well-known 'photoelectric effect' and b) thermionic emission. The former process is observed when the energy of the incident photon ($\hbar\omega$) is greater than the work function (A) of the surface; the excess photon energy being transferred to the released electron as kinetic energy. However, when very intense radiation fields are incident upon the surface, new multiphoton phenomena become possible such that $n\hbar\omega > A$ - an emission process that occurs for both solids and gases. The further phenomenon of above threshold ionization (ATI) in which the ionized electron acquires additional quanta ($s\hbar\omega$) from the radiation field is well-known for gas-phase atoms (Agostini *et al*[1]), but has only been suggested for solids.

The multiphoton photoelectric effect from a metallic surface has been the subject of several studies using first Ruby and now Nd:YAG lasers of short pulse duration (30 ns to a few picoseconds). (e.g.: Farkas *et al*[2]). However, only recently has the energy spectrum of the emitted photoelectrons been investigated. Luan *et al*[3] have reported a multi-peak structure for $n=4$ photon emission from a polycrystalline copper surface using a pulsed Nd:YAG laser ($\lambda=1064$ nm, pulse width 8.5 ns, intensity of the order of 10 $GWcm^{-2}$) focused at a glancing angle (89°) to the surface.

In this paper, we will report studies of electron emission from various metal surfaces (including silver and gold) using a 5 ns pulsed Nd:YAG laser ($\lambda = 1064$ nm, repetition rate 6-30 Hz) with provision for frequency-doubling. The average power density of the light pulse at grazing incidence to the sample is approximately $60MWcm^{-2}$. The emitted electrons are analysed using a single hemispherical analyser and detected on a channel electron multiplier. The emitted electron signal is strongly dependent upon the incident photon flux as multiphoton processes compete with thermionic emission.

Our latest results and a comparison with previous work of other groups will be presented at the conference.

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HOLOGRAPHIC RECORDING IN ALGAL SOLUTIONS

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Photorefractive crystals can record holograms in the form of phase gratings by their response to an interference pattern. Absorption of light generates electric charges which, diffusing from the anti-nodes to the nodes, modifies the refractive index by the Pockels effect. Algae, which exhibit photo-induced taxis, the movement towards or away from a light stimulus, may be thought of as behaving in an analogous manner, except that by their presence or absence they change the local transmission of a sample.

Cells of the flagelette Dunaliella Primolacta are contained in cuvettes at number densities of ~ 10^5-10^6 $m\ell^{-1}$. Both positive and negative taxis can be seen following illumination for periods of fifteen minutes up to a few hours by the beam from a 2mW He-Ne laser. In positive taxis, the algae congregate to form a spot on the input window, whereas in negative taxis, an annular pattern is generated with a distinct inner edge indicating that the maximum intensity for positive taxis is located at a certain radius of the laser beam's Gaussian profile. In this way the algae "print" themselves onto the inner surfaces of the windows during exposure. By monitoring the dependence of the optical density on light intensity and exposure time, a threshold stimulus, characteristic curve and speed may be obtained as for a photographic emulsion.

The ability of tactic cells to record simple holograms by this "printing" process was demonstrated by exposing them to the superposition of two coherent light beams with fringe periods ~ 50-100 microns, approximately 5-10 x the algal cell size. Subsequent reconstruction by a single beam produced diffraction out to second order, as expected from a thin grating corresponding to a monolayer of algae. Apart from the novelty of this biological analogue of an optical process, basic biophysical results are expected to be obtained; for example, by changing the spatial period of the fringes, the dimensions of the light intensity gradient producing algal taxis may be controlled to less than the cell size. Thus it should be possible to examine in detail the mechanism by which cells, moving at $mm.s^{-1}$, are able to distinguish between the nodes and antinodes of an interference pattern separated by only a few body lengths.

In this paper, details of the optical response of algal suspensions and the holographic experiments will be presented and discussed.

OPTICALLY-INDUCED VIOLATION OF TIME-REVERSIBILITY IN GaAs: PROBING BY TIME-RESOLVED MICROPOLARIMETRY

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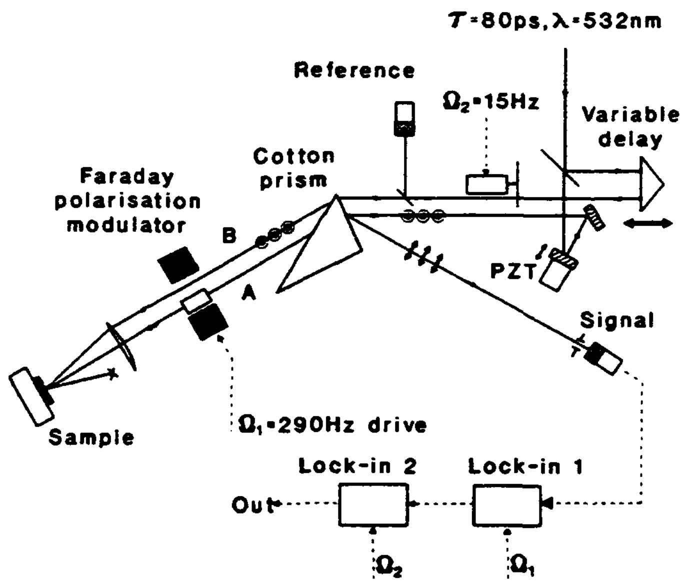
In this paper we present new optical phenomena of non-equilibrium media. Strong transient optical excitation of a crystal creates a nonequilibrium state and lifts the conditions for applicability of the principle of the symmetry of kinetic coefficients, leading to effects which are normally presumed to be forbidden by the time-reversibility principle[*]. In the zinc-blend material loss of the crystal equilibrium results in the appearance of the specular polarization effect of polarization rotation of a probe light pulse normally reflected from the crystal surface.

We report observation of a broken time reversibility state in a GaAs crystal as the result of optical excitation with picosecond pulses of second harmonic radiation from a cw mode-locked YAG laser. The effect is measured with a microradian sensitive time-resolved micropolarimeter. We found probe pulse polarization rotation of 10^{-5}- 10^{-4} rad which obeyed all the symmetry properties predicted for an effect due to the nonlocal time-non-reversible contribution to the optical response. The non-time-reversible state disappears during 100-300ps after termination of the transient optical excitation with at least two different decay constants. A microscopic mechanism of broken time reversibility is discussed, which takes into account mixing of conduction and hole bands in a non-time-reversible interaction due to spin-orbit coupling.



The figure shows the time-resolved polarimeter used in our experiment. It is sensitive to rotation of polarisation of probe beam (A) due to excitation of sample by pump beam (B), detected by using lock-in to detect at the frequency of chopping of the pump beam. The device has angular resolution of $\sim 10^{-6}$rad with 80ps time resolution.

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Photophysical and Photochemical Processes in Fullerenes under High Intensity Illumination.

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Abstract

Picosecond time resolved photoluminescence, photoconductivity and resonant Raman measurements are performed to investigate the influence of high intensity illumination on the properties of Fullerene single crystals. A highly nonlinear dependence of the luminescence emission efficiency and lifetime is observed on increasing the intensity. This nonlinear increase is associated with a dramatic shift to the red of the emission maximum. Under similar conditions, the photoconductive response of the fullerenes is also seen to increase nonlinearly with input intensity. Temperature dependent measurements indicate that the nonlinear processes are associated with an insulator-metal phase transition in the material. The transition is reversible and the observed photophysical changes coincide with a reversible shifting of the characteristic fullerene Raman resonances to lower energies. At extreme laser intensities, the shifting becomes irreversible, and a high molecular weight, insoluble material is formed. The photochemical process is proposed to be a polymerisation like reaction of the fullerene molecules in the triplet excited state. This is is supported by the observation that the rate of the reaction is greatly reduced in the presence of oxygen, an efficient triplet quencher. In conclusion, the response of Fullerene crystals to light is divided into three intensity regions. At low intensities the photophysical processes are characteristic of those of a molecular insulator, the electronic wavefunctions being molecularly localised. At higher intensities, the material undergoes an optically induced Mott-like transition to a semiconductor /metal, in which the electrons become delocalised in three dimensions. Further increases in intensity result in a photoinduced irreversible coupling reaction yeilding a high molecular weight material.

MULTIGIGABIT/S PULSE SOURCE BASED ON SWITCHING AN OPTICAL BEAT SIGNAL IN A NONLINEAR FIBRE LOOP MIRROR

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Sources of optical pulses capable of operating at a high repetition rate (from tens to hundreds gigahertz) are currently under considerable interest due to potential applications in ultra high bit rate telecommunication systems. In this paper we present a novel technique for high repetition rate pulse train generation based on reshaping of a dual frequency optical beat signal into a pulse train based on the use of a Nonlinear Fibre Loop Mirror (NFLM). The NFLM has recently been paid considerable attention as a fast optical switch for optical signal processing , for optical pulse shaping and in passively mode locked fibre lasers. Here, we demonstrate theoretically and experimentally how the nonlinear switching characteristics of the NFLM in conjuction with a dispersion delay line can provide a mechanism for the transformation of a beat signal into a train of well separated transform-limited pulses at multigigabit/s repetition rates.

The influence of the NFLM on the sinusoidal beat signal contributes to nonlinear amplitude shaping and phase modulation of its half-periods. The nonlinear amplitude transmission characteristic provides a higher transmission for peaks of sinusoidal envelope and relative suppression of the optical field around the minima. This leads to generation of a train of separated pulses. The periodicity of the generated pulses is then determined by the input beat frequency. Additionally, the pulses exhibit a frequency modulation (or chirp). However, this chirp is almost linear over the transmitted pulses forming the train, and is compensatable in an external delay line. The compensation can be achieved with a dispersion delay line based on a pair of diffraction gratings or using a piece of fibre in the anomalous group velocity dispersion region. The technique can generate a high quality train of well-separated transform-limited pulses with no pedestal or background between pulses. We report the experimental demonstration of the method. A 32 GHz train of 4.2 ps pulses has been generated at 1532 nm, and operation from 15 GHz to 50 GHz has been investigated.

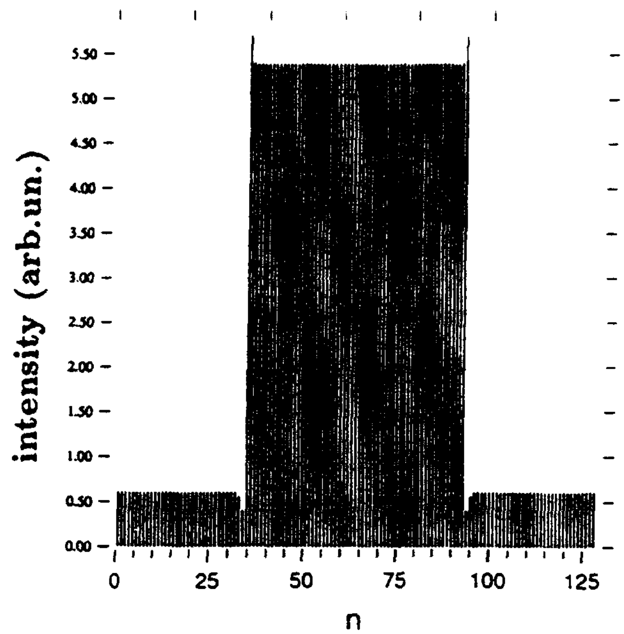

Fig.1 Transverse section of two-dimensional static pattern including two uniform distribution domains.

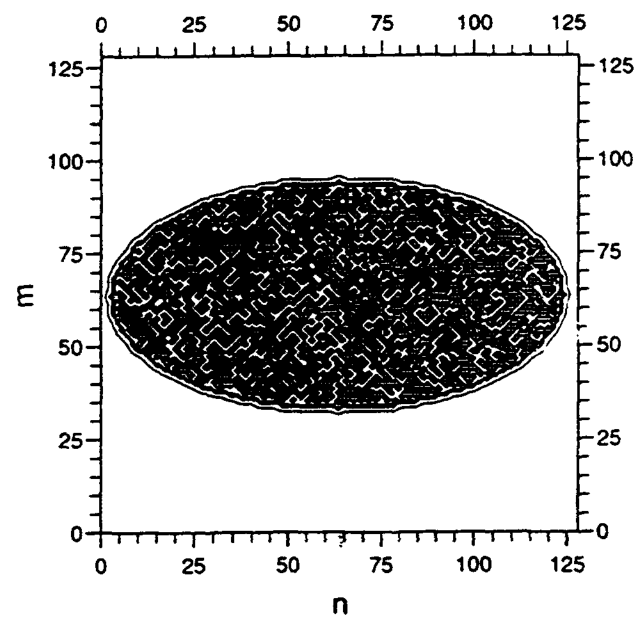

Fig.2 Two-dimensional static pattern containing distribution of binary "pixels" in its inner region.

SPONTANEOUS SPATIAL PATTERNS IN A LATTICE-LIKE NONLINEAR FABRY-PEROT ETALON

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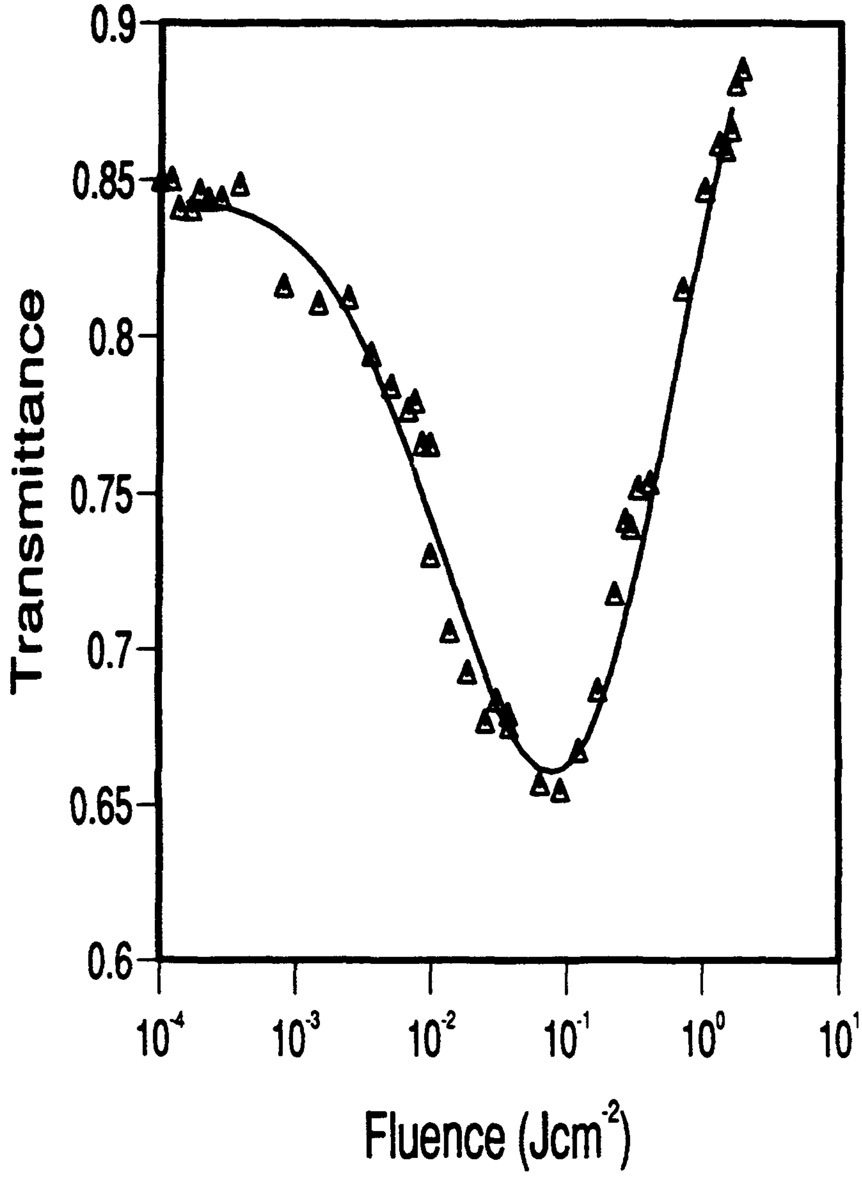
The problem of application of bistable optical elements as a logic or memory device in an optical data processing environment needs detailed consideration of transverse light dynamics in such systems in order to maximise the density of recorded and controlled information.

In this work we have considered the transverse dynamics of the light field in a Fabry-Perot (FP) etalon with a lattice-like internal structure (e.g. a fibre bundle or a network of coupled waveguides). The modulation of refractive index over transverse section causes the deformation and breaking of the dispersion relation connecting the propagation constant and transverse wave vector component, and causes the appearance of allowed bands separated by the forbidden gaps. The presence of forbidden regions can prevent the multiplying of high transverse frequencies. The introduction of these "insulator" properties permits the description of the light dynamics in a finite-dimension space on the basis of equations for the unit lattice cells coupled with each other by the convolution-like function.

The numerical simulation on a square lattice 128×128 has shown that the presence of a forbidden gap in a dispersion relation can provoke the stabilisation of spatially inhomogeneous structures. Excitation of an allowed band leads to the establishment of stable final patterns in the form of binary spatial noise with the auto-correlation function determined by internal structure of the band. That allows safe recording of binary-encoded infomation.

Examples of writing of patterns of various kinds will be given. These include domains of uniform (Fig.1) and quasi-random (Fig.2) excitation. Such patterns suggest possible application in neural networks and related fields.



Picosecond single-pulse transmittance measurement for HITCI. Reverse saturable absorption is seen for the lower input fluences and the reduction of absorption for higher fluences. Also shown is the theoretical simulation.

AN IMPORTANT PARADOX CONCERNING REVERSE SATURABLE ABSORPTION.

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Abstract

At high incident fluences the build-up of population in an excited state usually leads to a reduction of the corresponding absorption coefficient (saturation or bleaching). However, the absorption cross-section of the excited species may be sufficiently larger than that of the ground state species that the induced absorption overcomes the effect of saturation. This phenomenon has been reported for certain polymers and dyes [**1,2**], where the expression "Reverse Saturable Absorption" RSA has been used to describe the resulting transmission reduction. The RSA response associated with electronic transitions can be extremely fast, as a consequence of which there have been proposals for its application to laser mode-locking [**3**] and short-pulse optical limiting [**4**]. We point out, however, that once RSA action has set in, it does not necessarily continue to all higher fluences. The detailed behaviour will depend on the cross-sections and lifetimes of a series of excited states of the material. We report here, a fascinating paradox concerning the use of induced absorption at high fluences, namely the possible saturation of the reverse saturable absorption. This behaviour is demonstrated experimentally and explained in terms of a modified rate equation model. The role of parameters are discussed and with the aid of theoretical figures of merit, results are presented to show how this unusual effect may be overcome. From a computational point of view, a novel *physicists* approach is presented for progressing first order *stiff* [**5**] rate equations through a sample.

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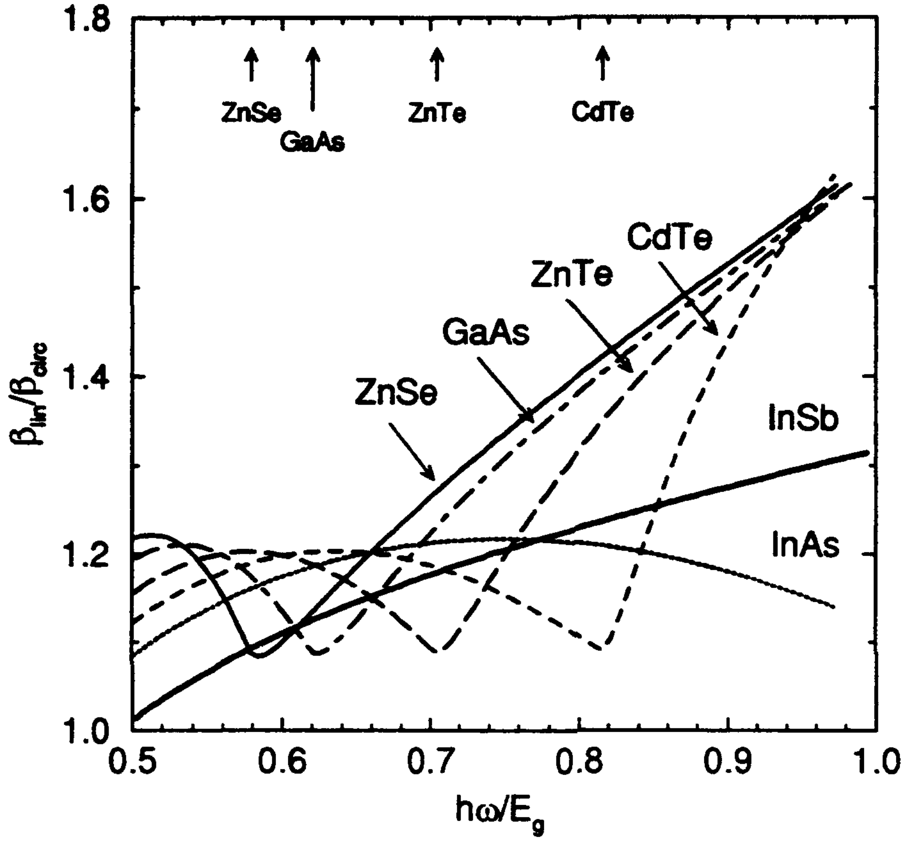

Fig. 1. Ratio of the calculated two-photon absorption coefficient for linear and circular polarisations (linear/circular dichroism) as a function of the ratio of the photon energy to band gap for the various III-V and II-VI semiconductors, InSb, InAs, GaAs, CdTe, ZnTe and ZnSe as indicted. The top arrows indicate the position of the threshold for transitions from the split-off band ($2\hbar\omega = E_g + \Delta$) for the various semiconductors indicated, which coincides with a predicted minimum in the linear/circular dichroism.

Linear/Circular Dichroism of Two-Photon Absorption in Zinc Blende Semiconductors

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Two-photon absorption in semiconductors is of interest as it has applications as a material probe and consequences for all-optical switching. To date, calculations and measurements of two-photon absorption coefficients have been mainly for a linearly polarised single beam [1,2]. Here we examine two-photon absorption for a circularly polarised light and consider the linear/circular dichroism (ratio of the two-photon absorption coefficient for linear and circular polarisations) in zinc blende semiconductors.

The bandstructure model used in this calculation is the isotropic model proposed by Kane [3] consisting of a conduction band, and heavy-hole, light-hole and split-off valence bands. By solving the **k.p** Hamiltonian numerically, nonparabolicity is included to all orders and exact electronic wavefunctions are employed. The resulting frequency dependences of the linear/circular dichroism of two-photon absorption for various III-V and II-VI semiconductors are shown in figure 1. The calculated values show a significant dependence on the presence of the split-off band, even in the case of the narrow gap semiconductors such as InSb. This is due to a partial cancellation of the contributions from the heavy-hole and light-hole valence bands in one of the third order susceptibility tensor elements. In the wider gap materials there is a pronounced minimum occuring at the threshold of two-photon transitions from the split-off band, which remarkably occurs at approximately the same value for the dichroism over a wide range of semiconductors.

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THE USE OF LASER PHOTODETACHMENT TO CHARACTERIZE ELECTRONEGATIVE DISCHARGES.

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Negative ions are known to be present in sizeable quantities in electronegative gas discharges. Their densities can be measured using a photodetachment technique to dissociate the negative ions into their constituent neutral molecules or atoms and electrons i.e.

$$X^- + h\nu \longrightarrow X + e \qquad (1)$$

where X^- is any negative ion and $h\nu$ is a photon with sufficient energy to photodetach the electron. A sudden local increase in electron density is created during the laser pulse. It can be shown that[1] this change in electron density is equal to the negative ion density.

A model of the subsequent change in the plasma dynamics following the laser pulse suggests that negative ion temperature can be inferred from the duration of photodetachment signal. For negative hydrogen ion measurements we are using a pulsed (10 ns) Nd:YAG laser which is passed through the discharge, co-axially onto a Langmuir probe. The photon energy of the Nd:YAG laser (1.2 eV) is sufficient to detach the electrons from the H^- ions whose electron affinity is 0.75 eV.

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AN EUV SOURCE BASED ON A SMALL SCALE LASER PRODUCED PLASMA AND MULTILAYER FILTER COMBINATION

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A laser produced plasma (LPP) is formed by focussing a laser pulse to an irradiance in excess of 10^8 W/cm^2 onto a solid target (usually *in vacuo*). In recent years LPP have moved away from being a source of purely spectroscopic interest [1] into the arena of applications [2]. Of all its many attractive features, the LPP single shot brightness is most responsible for this change in direction. A second technology also gaining acceptance outside the research laboratory is the layered synthetic microstructure (LSM) or multilayer [3]. We have combined these two technologies to produce an experimental system suitable for the study of the dependence of flux emission from LPP on laser, target and environmental parameters.

To date studies of flux emission from LPP have concentrated mainly on the X-ray range [4] while limited measurements exist for the EUV [5]. We will present results from our current study of the dependence of EUV flux on target atomic number and plasma production strategy.

Plasmas are produced by a Nd Yag laser (500 mJ, 10 ns.) focussed to a power density of ~ 10^{11} W/cm^2 via a f/5 lens. The detected flux is confined in a ~10 eV band centred @ ~138 eV as determined by the characteristics of the C/NiCr multilayer and thin film C/Ag composite filter used in our experiments. We have also recorded the spectrum of each target in the 138 eV region on a 2.2m McPherson spectrometer equipped with an EUV optical multichannel analyser and can interpret the target-Z dependence in terms of transition arrays between electron configurations of 5-15 times ionized species.

We have also measured the relative VUV flux in the Al transmission window (15 - 75 eV) from a ruby laser (1J, 30ns.) produced plasma for selected low, medium and high-Z targets. In this case the time history of the flux emission increases due to the persistence of VUV emitting lower ion stages.

Finally, following recent reports on picosecond [6] and femtosecond [7] double-pulse laser produced plasmas yielding increased X-ray emission,we have made a corresponding study with our table-top nanosecond source. Measurements of the EUV flux dependence on time, space and pre-pulse to main-pulse energy ratio have been made. We have observed up to a 40% increase in XUV flux (at constant laser energy) over single pulse produced plasmas.

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SURFACE PLASMON ENHANCED LASER ABLATION OF THIN METAL FILMS

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Surface plasmon (SP) enhancement of laser ablation of thin Al films is examined with a view to its application in metal film patterning and nano-structuring. Al films, deposited on silica prisms, are first characterised by attenuated total reflection using a broadband UV source and appropriate interference filter. The films are subsequently subjected to excimer laser radiation of wavelength 248 nm under conditions both of direct incidence from the air side of the film, and of SP excitation in which light is incident through the prism at greater than critical angle. For a given level of ablation damage in a particular film the fluence required using the SP technique is 5-10 times less than that needed when direct incidence is used. This is roughly in line with the energy absorbed in the film and would indicate the dominance of thermal processes rather than true ablative photodecomposition processes. This is perhaps rather surprising in view of the large field enhancement obtained on SP excitation. From a practical standpoint, though, it is clear that ablation of metal films can be achieved with much lower fluences than has hitherto been possible, thus reducing the requirements on laser output and relaxing the power handling constraints on any input optical elements.

RAPID PHOTON CORRELATION STUDIES OF RELAXATION IN MOLECULAR FILMS

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Light scattering has become a tool of choice to study thermally excited fluctuations at fluid interfaces. The spectrum of scattered light is just the power spectrum of the fluctuations, and reflects the interfacial properties affecting them. These include the viscoelastic moduli governing shear transverse to the interfacial plane and uniaxial dilation in that plane. Systems studied have included model membranes and monomolecular films of insoluble amphiphiles[1,2]. Spectral analysis by photon correlation provides more information than analysis in the frequency domain: dynamic light scattering is able to yield relative intensities[3]. This increased information content has proven useful in various studies.

When the surface is inhomogeneous, and thus the scattering signal is non-stationary, the usual methods of photon correlation average the fluctuations of the signal, thus losing information. Methods to acquire heterodyne correlation functions very rapidly permit the fluctuations of the signal to be followed in real time[4], allowing, for example, the direct determination of the sizes of phase separated domains in monomolecular films[2].

We have been applying these methods to the study of thermal fluctuations on the surfaces of soap solutions. In this case, these fluctuations are affected by many more processes and the interpretation of the results is challenging, particularly as theoretical treatments do not appear yet capable of quantitative prediction. However, our experiments appear to provide for the first time quantitative evidence of competition between different processes affecting the stability of the surface modes. In particular the values of the effective dilational surface viscosity are negative, indicating that some process is reducing the damping of the dilational modes below the expected values. More detailed investigations and analysis are in hand.

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SPECTROSCOPIC TECHNIQUES FOR INVESTIGATION AND CONTROL OF LASER ABLATION PLASMAS

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The plasma processes which occur during 248nm excimer laser ablation of YBCO high Tc superconductor targets in an oxygen atmosphere have been investigated for a wide range of ablation parameters using both emission and absorption spectroscopy techniques.*(1-4)* In the early high density stages of the plume expansion both techniques are subject to optical refraction effects. Reliable results can however be obtained in this region provided appropriate precautions are taken both in experimental design and interpretation of results. In the later stages of the plume expansion spatially and temporally resolved measurements using both techniques can provide an insight into both the physics and chemistry of the plume processes. In particular, efficient molecular oxide formation is observed at the contact front between the expanding plasma plume and the ambient oxygen atmosphere.

The target-substrate distance used for production of high quality *in situ* films is a function of the ambient oxygen pressure.*(5-6)* Spatially and temporally resolved profiles of the molecular oxide (e.g. YO) emission and absorption within the plume provides a convenient monitor both for control of the plasma parameters and for accurate location of substrates during thin film deposition.*(1-4)*

Recent results on both temporally resolved emission and laser absorption spectroscopy of the plasma plume will be reported.

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ION EMISSION STUDIES OF PULSED LASER ABLATION

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Dublin 2

Pulsed laser ablation has recently found widespread application in the deposition of a wide range of thin film materials. When excimer and Q-switched lasers are used the ablation plume is significantly ionised, and the ions have energies ranging up to several hundred eV. This paper describes the results of an experimental investigation to measure the flux and velocity distribution of the ions produced in the excimer laser ablation, at 248 nm, of $YBa_2Cu_3O_7$ and iron targets. The deposition rate was also measured, and compared to the ion dose in order to determine the ionic fraction in the deposition plasma. The dependence of the etching, deposition rate and ion velocity on laser fluence were measured and compared to the predictions of physical models of the laser ablation process.

PREPARATION AND OPTICAL AND MAGNETO-OPTICAL CHARACTERISATION OF Ba-HEXAFERRITE BY LASER ABLATION

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Oriented Ba-ferrite films with perpendicular magnetisation have been produced by Laser Ablation on (0001) single crystal sapphire, and fused quartz substrates. Results indicate that the in-situ growth of high quality Ba-ferrite on amorphous quartz is not possible because of the high substrate temperatures required to grow the appropriate crystalline phase. On cooling, the mismatched thermal properties produce severe cracking of the films when thicknesses are of the order of 200 nm. In addition, there is also some evidence of degradation of the film properties due to interdiffussion between the film material and the substrate. On the other hand, structural studies reveal that films deposited on crystalline sapphire substrates have a homogeneous single phase and are highly c-axis oriented with a crystalline size of ≈ 0.4 μm. Combined with the large magnetic anisotropy constant, this results in films with perpendicular magnetisation and an open hysteresis loop structure. The latter probably being caused by the effects of residual stress in the films.

Comparison of the optical and magneto-optical properties of the films with those predicted from calculations using the fundamental optical and magneto-optical constants of the single crystal material indicate that the film properties are similar to those of the bulk form.

The problem of particulate contamination has been markedly reduced by working at laser fluences of about 2 J/cm^2 and the effect of the condition of the Ba-ferrite target on the deposition rate and the material distribution in the plasma plume has been studied. Furthermore, because of the need, in optical and magneto-optical characterisation, for samples of uniform thickness we report on the successes of improving this by means of circular scanning of the laser beam over the target. Results are compared with theoretical simulations of the process using experimentally determined deposition profiles related to the material distribution in the ablated plume. Films of thickness which are uniform to within $\approx 10\%$ across a substrate of 1 m long have been fabricated.

SHORT-PULSE LASER PLASMA INTERACTION EXPERIMENTS AT IMPERIAL COLLEGE

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In recent years there has been considerable interest in the application of short pulse high power lasers. For example, when focussed onto solid targets intense short bursts of X-rays may be generated. These may have a variety of uses, for example, in biological imaging, and probing of ultra-fast phenomena in solid state physics. The interaction of a short pulse with an underdense pre-formed plasma may also allow us to investigate growth and saturation characteristics of phenomena such as filamentation, and stimulated scattering. These are subjects of great current interest in the ICF physics community.

At Imperial college we have started to investigate issues of relevance to these applications. Experiments have been carried out with a 1ps 1J Nd-glass CPA laser. When focussed onto solid targets an irradiance of 5×10^{16} W/cm^2 was achieved, with a pedestal of approximately 10^{13} W/cm^2 for 200ps, which pre-formed a plasma prior to the main pulse interaction. Under these conditions, we measured absorption and backscatter from solid targets as a function of angle and laser polarisation. The absorption was found to be insensitive to laser polarisation, and not very sensitive to incident angle. This suggests collisional absorption in a large pre-formed plasma is the principal absorption mechanism. We found a significant level (10-20%) of stimulated Brillouin back-scatter, but detected no stimulated Raman scatter. By imaging the back-scatter with spatial as well as spectral resolution, we saw that considerable self-focussing/filamentation of the beam can occur in the pre-formed plasma. There is some evidence that this is related to the production of hard X-rays with >100keV photon energy, which were detected via photomultiplier detectors coupled to CsI scintillators, positioned outside the target chamber. Also we have used a small portion of the pulse to form a frequency doubled probe with which we have measured density profiles and magnetic field generation. We have inferred B-fields of MG size, generated by the $\nabla N \times \nabla T$ mechanism. This is of considerable interest as the experiment is on a time scale more than an order of magnitude shorter than previously published work. In addition, we can infer that with a pre-pulse free system generating shorter density scalelengths, the B-field may be large enough to modify the hydrodynamic behaviour, with conseqent effects on the X-ray emission characteristics. Results of these ongoing experiments we be presented and discussed.

BEAM TRANSFER PROPERTIES OF HOLLOW SAPPHIRE FIBRE FOR HIGH QUALITY CO_2 LASER BEAMS

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In recent years, a number of different types of waveguide have been developed for the delivery of CO_2 laser radiation. Among these, hollow waveguides have shown favourable characteristics in terms of their power handling and mechanical properties [1,2]. In this paper we report on the beam transfer characteristics of a hollow sapphire fibre used for transmitting a high quality CO_2 laser beam (mainly the fundamental TEM_{00} mode). Although hollow fibre provides efficient power transfer, in the case of a high quality beam the degradation of the beam quality through the fibre may present a problem for some applications. In this work we have investigated the properties of a hollow sapphire fibre of 1 meter length and 1.08mm internal diameter. We have studied the dependence of the output power and beam quality on the alignment of the launch optics and the characteristics of the input beam. Our experiments reveal that the output beam profile of the fibre is more sensitive than the total power transfer to the launching condition. The internal diameter of the fibre was sufficient to yield low attenuation [3], for several low order modes, so that the fibre did not serve as an efficient mode filter. Even with a pure TEM_{00} input beam, higher order modes were observable at the fibre output.

The effect of this mode structure on the output profile is also enhanced by the fact that the waveguide modes are highly coherent, since they are generated by a single linearly polarised TEM_{00} input beam. The quality of the fibre-delivered beam is more likely to affect the application than the total power transfer, for the length and diameter of the fibre investigated in this work. We shall discuss the dependence of the output beam quality on the input conditions in terms of the superposition of waveguide modes at the output from the fibre.

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THE DETECTION OF SPUTTERED PARTICLES USING NONRESONANT MULTIPHOTON IONISATION

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Sputtering is the process where particles from the surface of a solid are removed as a consequence of ion beam bombardment. In the sputtering process, the number of neutrals sputtered is normally significantly greater than that of ions. To study the sputtering process, it is therefore desirable to detect the neutral component of the sputtered particles. An experimental system has been developed where nonresonant multiphoton ionisation (NRMPI) is used in the detection of neutral particles sputtered by ion beam bombardment of surfaces. The high intensity KrF excimer laser output at λ=248nm is used to ionise sputtered particles leaving the surfaces of Al, Cu and Si samples bombarded by a variety of incident ion beam species [Ar^+, N_x^+(x=1,2) and CF_y^+(y=1 to 4)]. The photoions produced were then analysed using a combination of time-of-flight and quadrupole mass analysers before being detected. The system provided the facilities for obtaining mass spectra and energy distributions of both ionic and neutral components of the sputtered particles. Recent results will be presented.

LINEAR and NON-LINEAR OPTICAL SPECTROSCOPY of METAL DERIVATIVES of FULLERENES

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Abstract. The fullerenes C60 and C70 have been prepared using the contact arc method, purified and used to synthesise metal derivatives. Compounds of C60 and C70 co-ordinated with the transition metals Iridium (Ir), Platinum (Pt), Palladium (Pd), and Molybdenum (Mo) have been thus obtained. These new materials have been fully characterised using the following techniques: Degenerate Four Wave Mixing, Saturation Spectroscopy, Fluorescence Spectroscopy and Linear Absorption Spectroscopy.

Results from these experiments have shown these materials to possess a sizeable optical non-linearity comparable to that of C60. The imaginary component of χ^3 as extracted from the Saturation Spectroscopy data, for the different derivatives, have values smaller than those of C60 and C70, but all the compounds exhibit "optical limiting" behaviour.

BROADBAND EXCITATION AND EMISSION OF SURFACE PLASMON POLARITONS

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The well known advantages of using surface plasmon polaritons (SPPs), notably the high sensitivity to surface adsorbates, are nearly always compromised in practice by the use of monochromatic excitation and the consequent lack of proper spectroscopic information. This limitation arises from the angle/wavelength selective nature of the SPP excitation. The work reported here uses an elegant broadband excitation technique, first described by Gruhlke and Hall[1], in a substrate (glass) - grating profiled photoresist - Ag film geometry. Laser radiation of wavelength 488 nm, incident through the glass substrate, excites by near-field coupling a broad band of SPPs at the photoresist-Ag interface within the spectral range of the photoresist fluorescence. With a judicious choice of grating period these SPPs can cross-couple to SPPs supported at the Ag-air interface. This latter mode can, in turn, couple out to light by virtue of the same grating period. The emission of light due to this 3-step process has been studied as a function of the angle of emission, wavelength and, importantly, depth of the (sinusoidal) grating profiled surface. It is found that the emission efficiency improves as the groove depth increases and does not saturate within the range of depth used in this study, 25-90 nm. The largest groove depth, 90 nm, is considerably greater than the optimum depth, 40 nm, required for SPP-photon coupling at a Ag-air interface or, in other words, for the last step in the process in isolation.

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Er^{3+}-LUMINESCENCE IN LASER DOPED SILICON

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We have carried out an investigation of the luminescence properties of silicon prepared by laser doping. The laser doping technique has been used in an attempt to increase the concentration of Er in the Si lattice. In this novel technique a silicon surface coated with a thin layer of the rare-earth metal is melted with a pulsed laser. The dopant is mixed in the molten layer, and incorporated in the crystal during the rapid re-growth. Er was chosen for the main part of our work as it is the best characterized of the rare-earth ions in Si.

The Er-coated samples were prepared using pulsed laser deposition from a solid Er target and a 23 ns excimer laser operating at 248 nm. A range of samples with Er concentration in the 0.1 - 2.5 x 10^{20} cm^{-3} were prepared. The laser doping was done, in air, using a single pulse from a similar excimer laser. Time-resolved reflectometry with a He-Ne laser was used to measure the melt duration, and so infer the melt depth.

In the photoluminescence (PL) spectrum of laser melted Si:Er, we observed several sharp PL lines between 1.52 and 1.58 μm. Comparing the wavelength, temperature dependence, and number of these peaks with previous reports on Er-luminescence, it is clear that they were due to the transitions between 4f-energy levels of Er^{3+} ions. Initial results suggests that this is a viable new process for the production of optically active Er in silicon.

We are presently investigating the effects of sample annealing on the Er^{3+} luminescence intensity.

TEMPERATURE DEPENDENCE OF LUMINESCENCE LINEWIDTH IN A TYPE II GaAs/AlAs SUPERLATTICE.

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We have measured luminescence from a GaAs/AlAs Type II superlattice and have found a strong reduction in linewidth as a function of temperature in the range 35K-2K.

The sample consists of a 130 periods of undoped 25ÅGaAs/48Å AlAs quantum wells. AlAs is an indirect semiconductor with the lowest electron level at the X point in the Brillouin zone, the hole level occurs at the Γ point as in GaAs. Electron confinement in the thin GaAs layer is large, leaving this level at a higher energy than the X state in the AlAs barrier. Significant optical absorption occurs only in the GaAs well due to selection rules but the electrons then scatters into the AlAs X level on a picosecond time scale. The structures is then a type II system with electrons and holes spatially separated in adjacent layers. The recombination process is indirect in both real and reciprocal space and the resultant radiative lifetime is very long at low temperatures. We have measured a lifetime of 10μs at a temperature, T=10 K. The luminescence spectrum at low temperatures consists of a main peak arising from a zero phonon process due to the breakdown of the K selection rule along the growth direction. These type of structures are known as pseudo-direct. Multiple phonon emission lines are also observed below this peak but they are much weaker.

We have measured the luminescence linewidth as a function of temperature under various excitation conditions. The sample was excited with light from a cw dye laser (DCM dye) at a wavelength above the direct band gap in the GaAs well. Luminescence was collected in a 2m Spex spectrometer with .5Å resolution.

We observed a strong reduction in linewidth from a FWHM value of 12meV at T=30K to a 7meV at T=4K. This reduction is very large in comparison with type I structures which have essentially a constant inhomogenous linewidth in this temperature range. We believe this effect to be due to the long carrier lifetime allowing very efficient carrier thermalization and also to the fact that the separated carriers form a system of aligned dipoles which can repel each other at short range. A similar effect has been observed recently in coupled quantum wells.[1]

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A MULTI-LASER, MULTI-CHANNEL SPECTROMETER FACILITY FOR THE STUDY OF THE INNER-SHELL EXCITATION OF ATOMS AND IONS.

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Growing interest in the fields of core excited atomic, molecular and solid species has resulted in a demand for compact, low cost laboratory sources in the extreme-ultraviolet (EUV) region of the spectrum. The measurement of photoionization cross-sections of free ions poses considerable difficulties as a suitable absorbing column, of adequate density, must be produced and backlighted by a bright, synchronised EUV continuum emitting source.

In contrast to the optical spectra of the valence electrons, which can mainly be described by the one-electron picture of the central field approximation, inner-shell excitations are characterized by strong many-electron effects causing the break-down of the simple one-electron picture. Photoabsorption experiments provide valuable information on these many-electron correlation effects in atoms and ions.

At Dublin City University, a multi-laser, multi-channel spectrometer facility for the measurement of photoionization cross-sections in the EUV, based on the Dual Laser Plasma (DLP) technique[1] has been developed. Using this technique the absorbing column is produced by ablation of spectroscopically pure targets by either a flashlamp pumped dye laser (~3 J in 1 μs) or by a Q-switched ruby laser (~1.5 J in 30 ns). The long pulse duration of the dye laser yields a relatively cool absorbing plasma suitable for the study of neutrals or low ionized species; the Q-switched ruby laser enables higher ion stages to be studied. Selection of the absorbing species is achieved by an appropriate combination of target irradiation, spatial and temporal resolution. A Laser Produced Plasma (LPP) is used to generate the synchronised EUV continuum source (10 to 300 eV) by focusing a Nd:Yag laser (1 J in 10 ns) on a metal of high atomic number; this continuum radiation passes through the absorbing column and is collected by a toroidal mirror which efficiently couples the light into a 2.2 metre grazing incidence spectrometer. The spectrometer is equipped with an MCP self-scanning diode array detector similar to that described elsewhere [2].

Key features of the system include resolving power (~2000), wide spectral coverage (20-200 eV), single shot sensitivity, linearity and versatility. Post data processing capabilities include the possibility of applying several methods of resolution enhancement.

The facility has been used to investigate inner-shell excitations of a wide range of atoms and ions existing in both their ground and excited states depending on the choice of absorbing plasma temporal and spatial characteristics.The performance, capabilities and versatility of the system will be demonstrated by providing recent results on a variety of atoms and ions to include He,Li,Mg,Al,Si,Ca, several of the transition metals and rare earth elements.

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THE GROWTH AND SPECTROSCOPIC CHARACTERISATION OF INORGANIC CRYSTALS HAVING THE STRUCTURE OF CALCIUM-GALLIUM GERMANATE DOPED WITH CHROMIUM IONS.

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Chromium doped $Sr_3Ga_2Ge_4O_{14}$, $Ca_3Ga_2Ge_4O_{14}$, $La_3Ga_{5.5}Ta_{0.5}O_{14}$, $La_3Ga_5GeO_{14}$, and $La_3Ga_5SiO_{14}$ are a family of crystals which shows excellent potential for application in solid state lasers offering wide tunability and the possibility of self-frequency doubling.

These crystals, with the space group P321, activated with 0.1 at% Cr are shown to exhibit luminescence from the chromium ion in the tri- or tetra-valent state in distorted octahedral sites of intermediate and weak crystal field strengths. We present detailed spectroscopic analyses of the laser excited luminescence R-line luminescence at 14K and room temperature and show by FLN studies that the large width can be attributed to inhomogeneous broadening due to the disordered nature of the crystal structure and that the decrease in the R-line intensity at room temperature is partly due to thermally induced inter-system crossing from the ^2E to the $^4T_2$ energy level of Cr^{3+}.

Strong visible absorption bands are observed around 460nm and 630nm which correspond to the $^4A_2 \rightarrow {}^4T_1$ and $^4A_2 \rightarrow {}^4T_2$ transitions of Cr^{3+}. These are accompanied by weaker bands ascribed to Cr^{4+} transitions. Each crystal has an inhomogeneously broadened luminescence band (ca 850nm → 1400nm) with strong electron-phonon interaction ($S \simeq 9$). Very interesting spectroscopic features are observed in the broadband emission which is comprised of overlapping spectra from chromium in the two valence states. A large blue shift of the peak of the broadband luminescence (ca $1000cm^{-1}$) is observed between 14K and room temperature which we interpret as the effect of non-radiative decay and the influence of thermal lattice expansion. The nature of these crystals reflects some properties similar to those of glasses and yet retains many unique features and characteristics of single crystals

CW OPTICAL PARAMETRIC OSCILLATORS

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ABSTRACT

Single frequency solid state laser sources coupled with improved nonlinear materials has led to advances in continuous wave optical parametric oscillators. Early work showed that cw thresholds could be as low as 10mW for monolithic $MgO:LiNbO_3$ doubly resonant OPOs (DRO) when pumped by diode-laser-pumped, frequency-doubled Nd:YAG. Conversion efficiencies of 80%, frequency stabilities of better than 10kHz and subharmonic phaselocked operation were demonstrated as was electric field tuning over more than 1THz frequency range.

Recent work has extended the cw OPO operation in three important aspects. First, a triply resonant OPO, constructed in a monolithic total internal reflection resonator (MoTIRR) geometry of $MgO:LiNbO_3$ has been demonstrated with a threshold for 1064nm pumping of less than 1mW. The incident 1064nm radiation is resonantly frequency doubled to the green which then pumps the OPO which oscillates near degeneracy. Second, a TIR OPO has been constructed of angle phasematched $LiNbO_3$ which is pumped at 1064nm and oscillates near degeneracy at 2μm. Threshold is observed at 150mW of 1064nm pump power. The monolithic structure allows for stable cw operation, however, thermal effects are evident in the tuning behavior. This critically phasematched cw OPO utilizes a unique TIR ring geometry resonator that allows efficient pump coupling and yet preserves a greater than 5000 finesse TIR resonator at the 2μm signal and idler waves.

The first cw singly resonant parametric oscillator (SRO) has been demonstrated. The cw SRO threshold is less than 2W when pumped by frequency doubled Nd:YAG. The pump wave is double passed through the KTP nonlinear crystal. The SRO demonstrates the expected continuous tuning behavior and the lack of cluster mode hopping that is evident in lower threshold DROs. The SRO operates in a single axial mode and has generated more than 1W of cw output at the nonresonant wave for 3.1W of pump power. Studies of the DRO to SRO transition have been done which show that the benefits of SRO tuning behavior can be obtained even with some feedback at the nonresonant wave.

Optoelectronics R and D for the 21st Century

Dr R G W Brown
Sharp Laboratories of Europe Ltd
Oxford

From the enormous breadth of subjects embraced by the term Optoelectronics, we will attempt to select topics that appear to have potential for future exploitation.

The talk will begin with motivations and current directions of research and development in Japan and the Far East, being the dominant commercial force today. Major contributions from elsewhere will also be brought into the picture.

In a "top-down" analysis we will attempt to draw out some of the research areas likely to have impact in the future, and speculate on research limits, new products and markets.

The talk is likely to focus on new semiconductor lasers and LED's; detectors and modulators; imaging, displays and printing applications, telecommunications and "intelligent" surroundings (using optoelectronics sensors, neural techniques, etc).

HIGH POWER CW SLAB-WAVEGUIDE MOLECULAR LASERS

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Recent advances in the understanding of instability processes and equivalent circuit modelling in transverse radiofrequency discharges [1] have established the conditions for the achievement of stable discharges at very high power densities (> $100W/cm^3$) between unballasted metal electrodes in the waveguide slab format. Experiments have shown that the near-electrode positive ion sheaths play a dominant role in stabilising RF discharges, and that the choice of excitation frequency is crucial. More generally, we show that there exist a set of *similarity relations* for RF discharges, which provide invaluable guidance in the selection of frequency, gas pressure and related parameters so as to maintain discharge stability and to ensure optimum laser pumping conditions. This is particularly useful in the quest for higher specific power extraction (power per unit area of electrode), which requires reduction in the inter-electrode separation [2].

Experiments [3] have shown that diffusion-cooled slab discharges provide excellent gain media for efficient power extraction from sealed carbon dioxide or carbon monoxide waveguide lasers. Specific power values in excess of $30kW.m^{-2}$ have been observed for CO_2 waveguide slabs, and about half this value for CO. In addition, operation of CO_2 lasers at 12% efficiency has been observed at the 200 W level at gas pressures of half an atmosphere, indicating potential for wideband tunability and the generation of cw trains of short pulses.

Results will be presented on the generation of high quality beams ($M^2 \leq 1.6$) at cw power levels in excess of 1 kW from a sealed slab waveguide laser, employing a hybrid waveguide-unstable resonator. Comparisons have been made of the characteristics of positive and negative branch confocal unstable resonators for the control of the beam quality in the lateral dimension of the in waveguide slab.

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Fig. 1

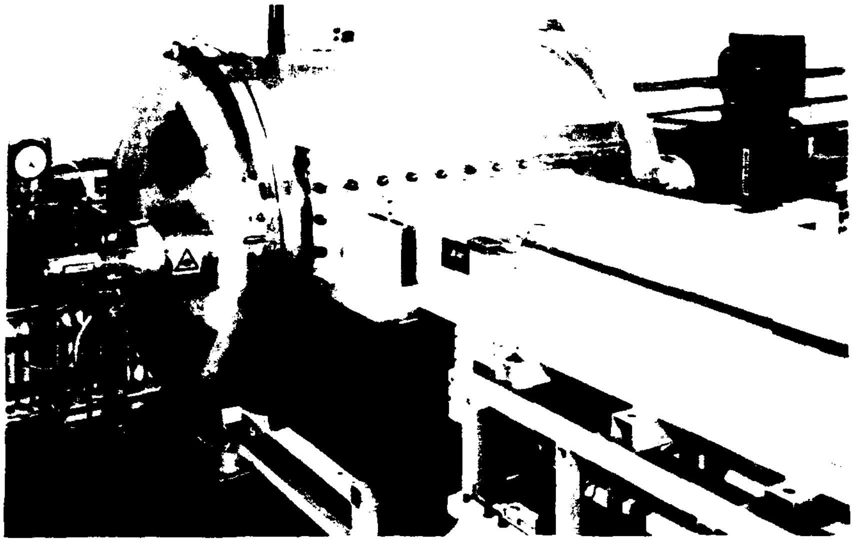


Fig. 2

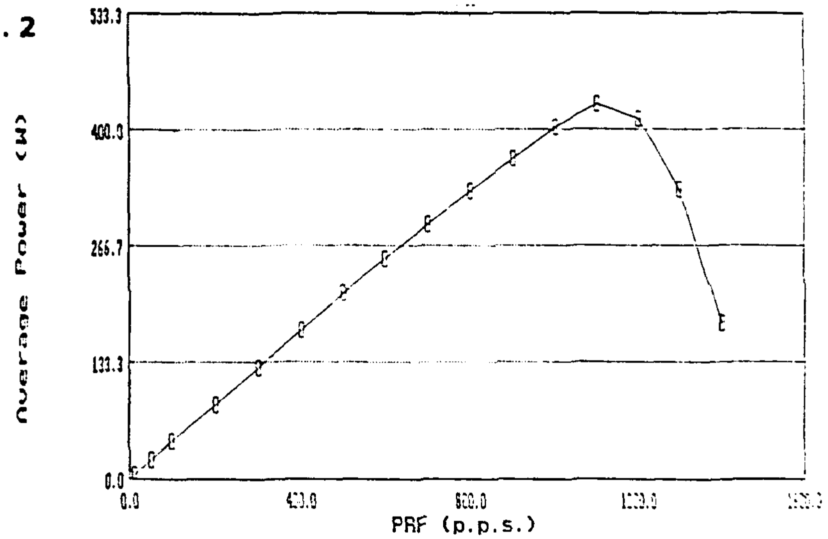
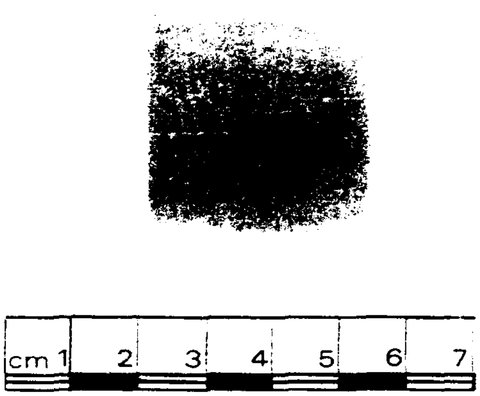


Fig. 3



THE CHIRP II HIGH POWER EXCIMER LASER

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As part of the Eureka EU213 Excimer laser programme, AEA has developed a compact, high average power high repetition rate excimer laser, CHIRP II, as shown in Figure 1. Operating on the XeCl excimer, powers of over 400 W have been achieved at pulse repetition frequencies (PRFs) of greater than 1000 pps (Figure 2). The onset of discharge instabilities sets the limit to the achievable PRF. The causes of these instabilities, their dependence on laser parameters and routes to their avoidance will be described with reference to experimental results.

The design of the system, in which safety plays a major part will be described.

The novel compact gas flow loop makes use of a single centrifugal fan and is contained within a single cylindrical vessel of 1.2 m diameter. The performance of the flow loop, and the effect of gas flow management on laser performance and PRF capability will be described. The flow velocity in the discharge region is 70 ms^{-1}.

The electrical circuitry includes a corona UV preioniser, which has a demonstrated lifetime in excess of 10^9 shots, and has been shown to be capable of initiating uniform, square cross-section discharges of up to 35 x 35 mm^2, Figure 3.

The laser performance, in terms of parametric optimisation, laser efficiency, beam quality and reliability will be described with reference to potential applications.

INVESTIGATION OF SUB-THRESHOLD TRANSVERSE LASER MODES

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A single-frequency laser must run on only one axial mode; it must also contain just one transverse spatial mode. The lowest order TEM_{00} mode is a common choice in many laser systems since higher order transverse modes can easily be eliminated by introducing a circular aperture into the cavity. However, it is difficult to assess just how far they have been suppressed below threshold. Hence, there is a danger that slight cavity adjustments may cause higher order transverse modes to rise above threshold, to the detriment of laser performance. We will describe a straightforward technique that allows accurate and detailed study of below-threshold spatial modes. Information can be obtained on the mode resonance frequencies, as well as proximity to threshold. The results also clarify the physics underlying the competition between different modes.

In our experiments, the output beam from a double-ended argon ion laser is passed through a pair of acousto-optic modulators. This allows a precise shift of the beam's frequency in the range 0 - $\pm$200 MHz. The shifted beam is then reinjected into the laser cavity; the output from the other end of the laser then displays a beat at the difference frequency and the strength of this beat is taken as a measure of the gain experienced by the reinjected beam. This gain shows marked resonance peaks when tuned around the vicinity of a sub-threshold transverse mode. Because of the orthogonality of transverse modes, the beat signal must be optimised by appropriate spatial filtering of both the input and output of the laser. Such filtering also acts as a discriminant between nearly degenerate modes. As an example, in our laser we can clearly distinguish between the TEM_{10} and TEM_{01} modes which have detunings of +26.2 and +28.3 MHz respectively, relative to TEM_{00}. The splitting is caused by the Brewster windows of the laser's discharge tube.

We have also observed that the enhanced gain close to a mode resonance is accompanied by a peak in the laser intensity fluctuation noise at the same frequency. This is a fundamental feature of all amplifiers: where there is gain, there must also be some noise. We have also used the technique to study competition effects between spatial modes, and a theory has been developed to try to explain these. Finally, we have followed the approach to threshold of the TEM_{01} mode, by studying the narrowing of its gain curve as the laser cavity is perturbed so as to suppress the TEM_{00} mode. The results allow us to quantify how far below threshold a transverse mode is lying.

SPRITE - A VERY HIGH BRIGHTNESS ULTRAVIOLET LASER SYSTEM

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The Sprite KrF/Raman laser system has been developed, over the last 12 years, into one of the world's brightest laser sources. It is now a fully-scheduled User Facility delivering more than 1900 shots per year to a dedicated target chamber. It can be set up for operation in a number of different configurations, and upgrades have recently been implemented which have extended the performance of several of these. It also supports a substantial laser development programme, addressing the future requirements of the high-power laser community.

Sprite has traditionally been operated as a KrF-pumped Raman laser[1], delivering 10 ps pulses of very high brightness at 268.0 nm. Raman operation also yields an exceptional prepulse contrast ratio ($>10^{10}$). Improvements to the transport optics have now increased the beam brightness to $>10^{20}$ W cm^{-2} sterad^{-1}. The system is reaching the theoretical limits of conventional Raman amplifier efficiency and of pulse length, so brightness increases will in future require higher pump energy and/or better Raman beam quality. Both of these courses are being pursued as part of the facility's Enhanced Raman programme. A novel type of pulse-shortening using Raman pulse-compression has also been studied and initial experiments have yielded pump-to-Stokes compressions of more than 6 times (from 16 ps to 2.5 ps) with energy conversion efficiencies of 30%. This may allow the brightness limits to be extended still further.

Direct amplification of pulses as short as 3 ps is practical in the Sprite KrF chain. The energy from the 27 cm diameter final amplifier is then typically 1.4 J, limited by nonlinear absorption in the silica output window. Until recently static aberrations in the optical system degraded the KrF beam quality to 10-20 times the diffraction limit, setting the maximum 3 ps brightness to $\sim10^{18}$ W cm^{-2} sterad^{-1}. The static beam quality has now been improved to ~2 times diffraction-limited, at which point transient B-integral effects in the air and in downstream optics are expected to become significant. Sub-picosecond pulses have been amplified through the KrF chain and the threshold for B-integral effects has been clearly established. Amplification of very short pulses is now being pursued via a CPA programme, whose results will be reported elsewhere[2].

The next KrF laser to be installed at RAL will be the new 40 cm amplifier, Titania, which is designed to deliver 430 J in 96 10 ps pulses. This module is now being assembled and details of the associated 200 J Raman system are being finalised.

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REFLECTANCE MODULATION PROPERTIES OF DBR SURFACE EMITTING LASER DIODES

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The dynamical characteristics of DBR SELD subject to high-frequency electro-optic modulation of Bragg mirror reflectance are studied.It is shown that the modulation response at high frequencies is more efficient than conventional current modulation. In combination with such direct current modulation the present loss modulation scheme offers possiblities of achieving pure frequency modulation or the elimination of relaxation oscillations.

With a view to avoid relaxation oscillation limitations of directly modulated semi-conductor lasers several novel modulation techniques have been proposed recently . Practical difficulties associated with the concepts of laser gain [1] and spontaneous emission [2] modulation have motivated the present study of using a combination of direct current modulation and control of the cavity photon lifetime to effect laser modulation. Support for the present approach is found in a recent experimental realisation of electro-optic tuning of distributed Bragg reflectors in surface emitting laser diodes [3].

A small signal analysis of the laser response to pure photon lifetime modulation shows that, in contrast with conventional direct curent modulation,the modulation response decays at high frequencies only as 1/w. A similar 1/w response had been predicted for laser gain modulation via carrier heating [1].

For a Bragg reflector fabricated from alternating GaAs/AlAs lasers the electro-optic effect changes the refractive index of the direct band gap GaAs only.This alters both the amplitude and phase of the Bragg mirror reflectivity.It is found that for refractive index changes of only .001 a lasing wavelength shift of about 100 A occurs.By proper control of amplitude and phase of current and photon lifetime modulation amplitude modulation can be eliminated. Alternatively relaxation oscillations can be eliminated though in this case the light modulation will be of well-developed amplitude-frequency type.

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MODELOCKING AND SHORT PULSE PRODUCTION IN A MULTIPLE QUANTUM-WELL LASER DIODE BY OPTICAL PULSE SYNCHRONOUS PUMPING

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We have studied the dynamics of a synchronously modelocked external cavity multiple quantum well diode laser. The laser diode was pumped via its facet using the modelocked pulses from a Pyridin 2 dye laser. These pump pulses are about 5ps duration. This results in ultrafast modulation of the carrier density in the laser active region. While similar experiments using gainswitched laser diode pulses of 45ps duration have been reported [1], our experiment capitalizes on the principal advantage of optical pumping in that the pump pulses are far shorter than can be applied electrically.

Single light pulses shorter than 3ps in duration were obtained from the laser diode external cavity. Multiple subpicosecond pulses separated by the diode laser round trip time have also been observed.

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Carrier pinning by mode fluctuations in laser diodes

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The gain spectrum of a semiconductor laser diode (LD) or edge-emitting light emitting diode (LED) is directly related to the active region carrier density (n). The LD gain spectrum may be obtained [1] from the modulation depth of below threshold Fabry-Perot fringes in the emission spectrum. When high quality antireflection coatings are applied to both LD facets the device becomes an LED and a different method is needed to determine LED gain spectra. We make use of the fact that spontaneous emission experiences amplification while propagating along the LD or LED index guide. In contrast, non-guided light, which is measured after passing through a window in the substrate, does not experience gain. The intensity of this window light, L_W, is proportional to the spontaneous emission rate per unit volume per unit energy interval. Gain as a function of photon energy may be calculated from the spontaneous emission spectrum taking into account conduction band non-parabolicity and the presence of both heavy- and light-hole valence bands [2]. Light emitted from the facet experiences gain or loss and hence n may be obtained by comparing the ratio of measured emission spectra from the facet (F) and the window (W) of a LED with the model.

Our results show that carrier pinning in the LED is both less substantial and less temperature sensitive than in the LD. Photons fluctuating into cavity modes of the laser cause carrier density to be pinned more effectively than in the corresponding LED device. Thus, to reach lasing threshold, it is necessary to provide an extra current, I_{th}^{nom}, to over-come the effects of this pinning. In fact, I_{th}^{nom} accounts for almost half the LD threshold current, I_{th}. At elevated temperatures carrier density at threshold increases so that the relative importance of fluctuations is enhanced and I_{th}^{nom} increases. These results imply that I_{th}^{nom} plays an important role in determining the temperature dependence of threshold current in long wavelength laser diodes.

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INFLUENCE OF SPECTRAL BROADENING ON GAIN AND RECOMBINATION IN SHORT WAVELENGTH QUANTUM WELL LASER DIODES

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The large number of carriers injected into a semiconductor laser under operation means that their interaction with one another is an important consideration in modelling laser diodes and non-linear optical phenomena. This leads to an energy broadening of any optical transition between electron and hole states and thus it is important to include these effects when calculating optical gain and spontaneous emission spectra. We have calculated the energy state broadening due to electron-electron, hole-hole and electron hole scattering from first principles, using an Auger-type process. This has been incorporated into a model to calculate spontaneous emission spectra which can be compared with experimental data. This model is the basis of calculations used for the optimisation of device structures for low threshold operation.

Direct measurement of optical gain and recombination current in semiconductors is difficult and it is common to rely on calculations or to derive gain spectra from experimental emission spectra. We will show examples of this process for visible emitting (623-660nm) GaInP/AlGaInP strained layer quantum well structure, and will examine the validity of this approach in the presence of spectral broadening by a lifetime which is dependent upon the energy of the initial and final states. The implication for threshold current calculations will also be discussed.

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TURN-ON JITTER OF SEMICONDUCTOR LASERS IN SHORT EXTERNAL CAVITIES

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Turn-on delay jitter is of considerable importance for practical applications of semiconductor lasers.The jitter causes a degradation of the temporal resolution and acts as a limiting factor in the performance of high-bit rate optical communication systems.It is well-known that optical feedback effects need to be taken into account when considering the performance of laser diodes in optical communication systems.However, few studies are available of external cavity effects on laser diodes under modulation conditions or in the transient regime following gain-switching.The characterisation of jitter properties associated with turn-on dynamics of external cavity semiconductor lasers is thus considered to be a worthwhile task .

Analytical expressions ,validated by numerical simulations, have been obtained for the turn-on delay jitter of semiconductor lasers subject to weak optical feedback in short external cavities.The results demonstrate explicitly that displacement of the external reflector on optical wavelength scales causes significant changes in the switch-on dynamics of the laser.It is found that more than a 400 % increase of jitter can occur under certain circumstances.The sensitivity of laser switch-on dynamics to reflector location is considered to be relevant to the performance of packaged laser diodes.

Acknowledgments

E.H-G.C.M. and M.S.M. acknowledge financial support from the Comision Interministerial de Ciencia y Tecnologia, Project TIC90/080. K.A.S. acknowledges support from the University of the Balearic Islands where the present work was undertaken. Helpful discussions with S.Balle are also acknowledged.

QUANTUM WELL STRUCTURES FOR SUB-MILLIMETRE OPTICAL RECTIFICATION AND FREQUENCY DOUBLING

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Intersub-band processes in asymmetric semiconductor quantum well structures are of interest for a variety of optical processes responsive at THz frequencies . Interest has been shown ,in particular,in the nonlinear optical properties of such structures including nonlinear refractive indices . In the present work the optimisation of optical rectification and frequency doubling at sub-millimetre wavelengths using quantum well structures has been undertaken.

The central issue in the optimisation of quantum well structures for optical processing is the design of structures whose electronic wavefunctions maximise the appropriate nonlinear optical coefficient. In the case of optical rectification two quantum states need to be taken into account . Optimisation then involves reconciling the requirements of maximising (i) the overlap between the wavefunctions and (ii)the difference between the centroids of the wavefunctions for the two quantum well states. For frequency doubling ,on the other hand, account is taken of three quantum well states but the essential requirement is to maximise the overlap between all pairs of the three wavefunctions .

Electronic wavefunctions in asymmetric and graded quantum well structures have been calculated using a *simple but efficient* numerical technique which exploits the analogy between optical waveguides and quantum well structures.Attention has been given to a Coupled Asymmetric Graded Quantum Well structure.Optimisation of the structure in terms of well grading and step distance has been undertaken both for optical rectification and frequency doubling coefficients of the structure.

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MODIFIED BANDWIDTH K-FACTOR DUE TO PARASITICS IN LASER DIODES

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The characterisation of the useful bandwidth of laser diodes is of considerable importance for practical applications of these devices in high speed optical communications systems. Olshanksky introduced a so-called K-factor as a simple means for calibrating laser diode bandwidth [1].In recent work it has been shown that the impact of gain nonlinearities on laser diode bandwidth can be well-represented by an alternative bandwidth parameter [2,3].

In practical applications the modulation response of laser diodes is also affected by parasitic effects arising both within the laser chip and due to packaging of the laser.In the present paper it is shown that the influence of such parasitic effects can be accomodated by the use of a modified K-factor.It is indicated also that parasitic effects related to carrier transport effects in quantum well devices can be treated within the proposed formalism.

The modified K factor is found by using a third order response function obtained by combining the intrinsic second order function of the laser diode with a first order low-pass response function for the parasitics.A cubic equation in the square of the bandwidth is then obtained from which an analytical expression for the maximum extrinsic bandwidth of the laser has been derived .The expressions so obtained give a convenient means for assessing the effect of parasitics on laser diode modulation performance.A similar third order response function is shown to be appropriate to the treatment of carrier transport effects in quantum well lasers and hence corresponding results for bandwidth modification are obtained directly form the present analysis.

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QUASI-THREE-LEVEL LASER OPERATION OF YB:YAG WAVEGUIDES

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The main advantage of using waveguides in laser systems is that they produce high pump intensities over long interaction lengths for low input pump powers. This should lead to lower thresholds and more efficient lasers. Often though extra loss due to waveguide propagation reduces the benefits of this confinement. However in three-level and quasi-three-level laser systems there already exists absorption loss at the laser wavelength due to thermal population of the lower laser level. Any added waveguide propagation loss will therefore not have such a significant effect on laser performance. An example of such a laser system is Yb:YAG where 4% of the total population resides in the lower laser level. For a 6.5 at.% doped sample this is roughly equivalent to a propagation loss of 2.5db/cm which for the guides discussed here is the main contribution to the loss. The laser performance of Yb:YAG has been measured in planar waveguides made by two methods - ion-implantation and epitaxial growth.

An ion-implanted Yb:YAG guide was fabricated by implanting He^+ ions with energies up to 2.65MeV into the crystal face. This gave a guide with losses of ~2dB/cm which produced a laser spot size of 2.5μm in the guided direction. Using HR mirrors this lased with an absorbed power threshold of 30mW. A slope efficiency of 19% and a threshold of 75mW was obtained when one mirror was replaced with an 83% reflectivity output coupler. Improvement of these results could be made by moving to a channel geometry as has been successfully demonstrated in ion-implanted Nd:YAG.

Planar guides have also been fabricated by liquid phase epitaxial growth of a 6μm Yb,Ga,Lu:YAG layer on top of a pure YAG substrate. These have much lower loss (~0.2dB/cm) than the ion-implanted guides and therefore the guide loss makes very little difference to the laser performance. With an 83% reflectivity output coupler the threshold is 14mW and the slope efficiency 28%. This compares very favourably to similar bulk experiments. Again the move to a channel would further enhance the laser performance. Methods for doing this are currently under investigation.

THE EFFECT OF RESIDUAL SPATIAL HOLE BURNING IN UNIDIRECTIONAL RING LASERS

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A convenient way to achieve efficient single frequency output from a homogeneously-broadened solid-state laser is by using a resonator configuration in which spatial hole burning is avoided. One of the most frequently used techniques employs a unidirectional ring resonator configuration. This approach has proved very successful, particularly with miniature diode-pumped solid-state lasers, and has led to a number of reliable single frequency laser devices (e.g. [1],[2]).

One important feature of this technique, which is often overlooked, is that there is usually present a small amount of residual spatial hole burning, which arises as a consequence of back reflections from resonator components (e.g. imperfect antireflection coatings). The extent to which spatial hole burning occurs is determined mainly by the choice of resonator design and is most pronounced for ring resonators in which the gain medium is in close proximity to a high reflecting mirror. One example of such a resonator would be a monolithic resonator (e.g. [1],[3]), where the dielectric mirrors are coated directly on to the surface of the laser medium. Here, spatial hole burning occurs in the region of the gain medium where the incident and reflected laser beams overlap. Although this region of overlap is usually very small, the resulting spatial hole burning can nevertheless have a significant effect on laser behaviour and, in some circumstances, can limit the maximum single frequency power which can be obtained from the laser.

In this paper we discuss the effect of residual spatial hole burning in unidirectional ring lasers and present a quantitative model which allows us to estimate the maximum single frequency power which can be obtained in any given situation. Using our model we are also able to suggest a strategy for the design of improved single frequency ring lasers with higher output powers.

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OPTICAL SPECTROSCOPY OF TRANSITION-METAL-ION-DOPED MATERIALS FOR SOLID-STATE LASERS

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The success of new tunable solid-state lasers, based on Cr-doped forsterite and Ti-doped sapphire, has stimulated a search for new materials doped with transition metal ions which emit efficient broadband luminescence at room temperature. While laser action has been achieved in several Co and Ni-doped materials at low temperatures, quenching mechanisms such as non-radiative relaxation and excited state absorption have prevented all systems based on these ions (except MgF_2:Co) from operating at room temperature. As part of an on-going search for potential new laser media in visible and near infra-red regions, we have made detailed absorption, luminescence, and decay time measurements of several Co and Ni-doped samples over a range of temperature from 4 K to 300 K. In $MgNb_2O_6:Ni^{2+}$, strong visible and IR bands are observed. The lifetime of the visible emission is unusually short ($\approx$ 30 ns), which may explain why (in contrast to other Ni-doped systems), this band is not quenched by non-radiative processes at room temperature. In the same material doped with Co^{2+}, a strong band (which is not thermally quenched) is observed at 850 nm. This unusual emission (lifetime at room temperature $\approx$ 3.5 μs), which is not observed in other Co-doped media, is ascribed to the $^4A_2 \rightarrow {}^4T_2$ transition on the Co^{2+} ion in an octahedral field. Luminescence, excitation, and lifetime measurements of other new potential laser media - $ZnAl_2O_4:Ni^{2+}$, $ZnNb_2O_6:Ni^{2+}$, and $LiGa_5O_8:Ni^{2+}$ - will also be presented. Detailed measurements of the temperature dependence of the intensity and lifetime of the luminescence will be discussed and we will attempt to fit this data to the predictions of established theoretical treatments. The results provide some useful guidelines for future research aimed at obtaining laser action in the near infra-red based on Co and Ni-doped materials.

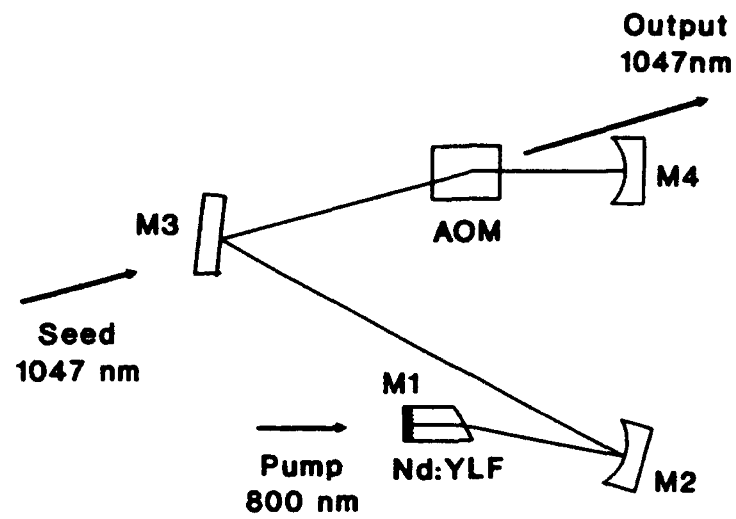
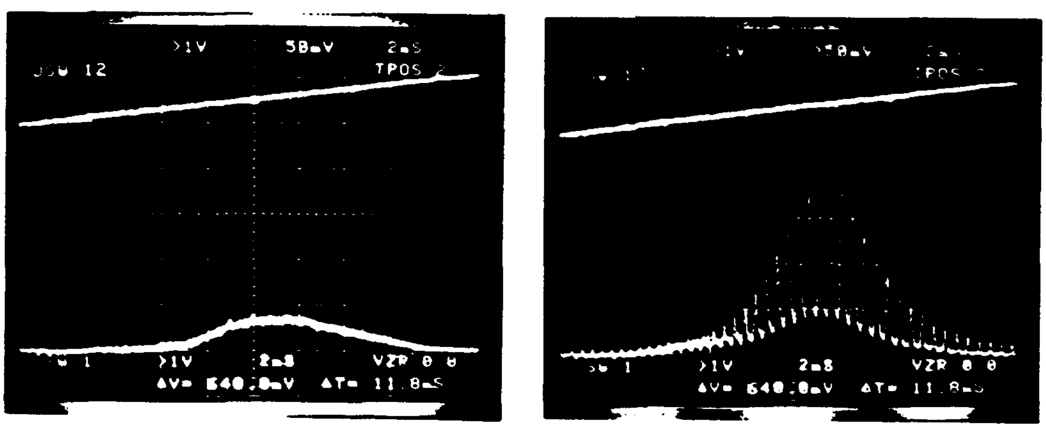


Fig. 1. FSF cavity configuration. M1, M2 and M4 are high reflectivity mirrors; M3 has 5% transmittance to allow injection -seeding of the FSF laser. AOM is an acousto-optic modulator (continuously driven Q-switch/frequency shifter).



(a) (b)

Fig. 2. Typical optical spectrum of FSF laser sampled using external etalon set over a given 1.5 GHz window (lower traces). (a) Free-running operation. (b) Seeded operation.

FREQUENCY-SHIFTED FEEDBACK IN A Nd:YLF LASER

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We describe the performance of a Ti:sapphire pumped Nd:YLF laser incorporating frequency-shifted feedback (FSF), when free-running (unseeded) and when injection-seeded with a single frequency master oscillator. The laser cavity is depicted in Figure 1. The frequency-shifting action of an intracavity modulator was used to suppress the axial mode structure of the laser, resulting in the generation of a continuous frequency spectrum with a 140 GHz bandwidth. The continuous nature of the free-running laser spectrum was verified by heterodyning the FSF laser with a single frequency Nd:YLF laser tuned over the laser bandwidth. The laser threshold was 200 mW with a power slope efficiency of 25%. The low coherence of the free-running laser makes it a suitable source for low noise fibre-optic sensors and for the optical cooling of atoms. Heterodyning the FSF laser with a single frequency source also provides a simple scheme for measuring the frequency bandwidth of fast photodiodes.

The single frequency Nd:YLF laser was also used as a master oscillator to injection-seed the FSF laser. This resulted in the generation of a discrete multi-frequency spectrum (or comb). The output of the FSF laser was monitored with a 7.5 GHz scanning confocal interferometer with a resolution of 50 MHz, placed after a series of extracavity etalons producing sample windows with a 1.5 GHz bandwidth. Figure 2(a) shows the sampled laser spectrum in the absence of a seed signal for a pump power of 2 W. The continuous nature of the spectrum is clearly observed. On applying 20 μW of seed signal at a frequency offset of - 80 GHz from the laser centre frequency (the modulator being set for frequency upshifting), the continuous spectrum was replaced by a discrete multi-frequency spectrum as shown in Figure 2(b). Similar discrete spectra were obtained for all sample windows, indicating comb generation was achieved over the entire 140 GHz laser bandwidth. The non-resonant nature of comb generation in the FSF laser makes it particularly suitable for applications in spectroscopy and metrology.

FSF operation has previously been reported in organic dye and semiconductor diode lasers [1,2,3,4]. In these cases, the fluorescence lifetime of the metastable laser level has been short with respect to the cavity lifetime. Since the dynamic behaviour of the FSF laser results from the interplay between gain saturation and active frequency shifting, the relatively long upper state lifetime of the excited Nd ion of 430 μsec (in comparison to a few nanoseconds typically in dye lasers), leads to a driven relaxation oscillation that has not been reported previously. A discussion of this oscillatory behaviour and potential applications of the FSF laser will be included in the presentation.

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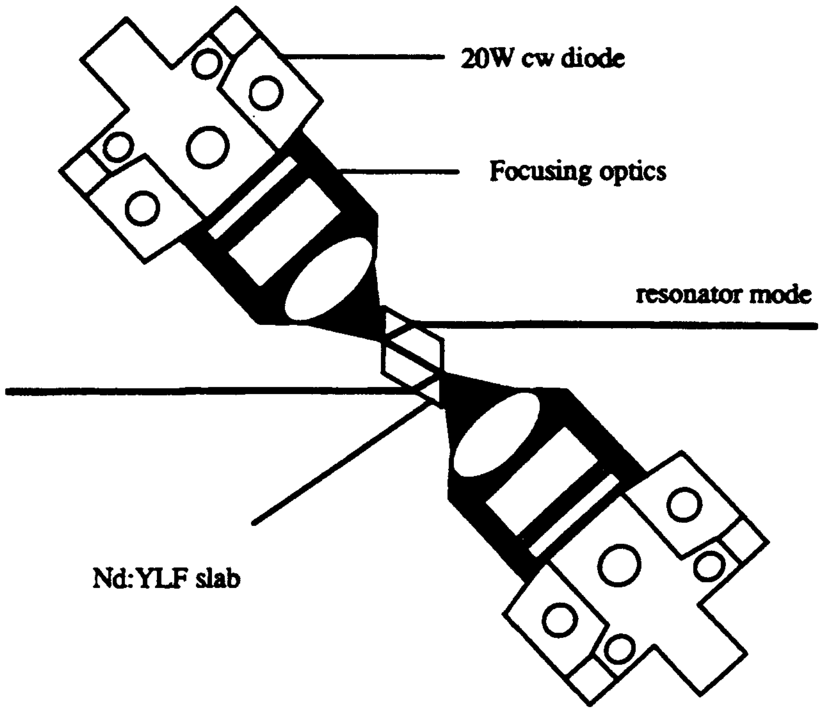

Fig. 1: Pump Configuration

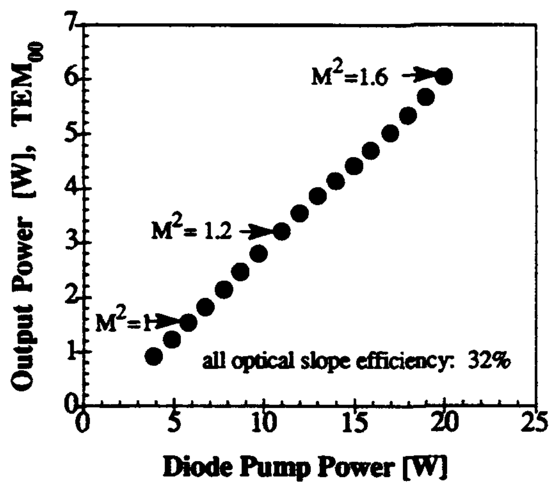

Fig. 2: Input power versus output power and measured magnifications

SCALABLE CW DIODE END-PUMPED ND:YLF SLAB SYSTEM

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Nd:YLF is a promising material for high power continuos wave (cw) applications because its natural birefringence dominates over any thermally induced birefringence at these pump powers.

Employing an end-pumped diamond-shaped Nd:YLF slab (Fig. 1), we achieved 6W output power at 1047nm (Fig.2) with a minimally thermally distorted TEM_{00} mode (measured magnification $M^2 = 1.6$) using a 20W cw diode pump module. This corresponds to an all optical efficiency of 30% in the TEM_{00} case (32% slope efficiency) and 34% (6.8W) in case of a multimode output.

To combine the well known advantages of the high extraction efficiency of end-pumped systems with the easy scalability of side pumped systems there are basically two known approaches. One of these uses multiplexed end pumped rod systems, the other one employs zig-zag path slab systems [1], which are pumped along the resonator path at the reflection points, using suitable focusing optics [2].

The latter approach has the advantage of an easier mechanical set-up and, more importantly in the case of YLF as its thermal shock parameter R is 5 times less than YAG, a better thermally induced stress resistance.

We will present some thermodynamical considerations for determining the dimensions of the Nd:YLF slab to reduce the thermal fracture problem in end-pumped YLF systems, as well as temperature and thermal lensing measurements to optimise the resonator configuration.

All this enables us to pump an integrated gain region of approximately 0.6mm x 1mm with a nominal 20W without the occurrence of thermal stress damage while maintaining the high all optical efficiencies mentioned above. Therefore YLF is not limited by its brittleness in comparison to YAG at these power levels.

The present scheme allows for doubling of the input power up to 40W by the use of a second diode, so that output power in excess of 10W TEM_{00} should be possible with this compact YLF system.

The long fluorescence lifetime associated with Nd:YLF makes it a promising material for cw-pumped Q-switching, and we are presently undertaking some studies.

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STUDIES OF AN INJECTOR-AMPLIFIER XUV LASER SYSTEM

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A new injector-amplifier facility has been developed for collisionally excited XUV lasers. The plasma amplifiers are pumped with a total power of $\approx$ 2kJ/1ns from eight optical beamlines of the VULCAN glass laser at the SERC Central Laser Facility. The amplifier architecture is designed to maximise the coherence and brightness of an XUV laser beam with a view to providing a beamline for applications utilising photons in the λ = 15 -25 nm wavelength range.

The system has initially been tested as a 3p-3s neon-like germanium (Ge XXIII) laser operating on transitions at $\lambda \approx$ 24 nm. A double plasma, refraction-compensating system which has been described elsewhere [1] is used as a source producing an output beam of amplified spontaneous emission of relatively poor spatial coherence. This beam is injected into a separate plasma amplifier using a concave XUV mirror to control the intensity and divergence of the coupled radiation and thereby to control the coherence of the injected beam.

The polar distribution of the output beam in several coupling geometries is studied and measurements made of the degree of spatial coherence achieved.

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PROPAGATION OF INTENSE PICOSECOND LASER PULSES IN DENSE GASES

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When an intense picosecond pulse propagates through a gas at near atmospheric density it is found that the pulse spectrum may alter dramatically. When sufficient ionisation due to the pulse occurs, the spectral modification is due to a rapid modulation of the plasma refractive index, this being dependent on the free electron number density. There is an asymmetric spectral broadening to the blue with no shifting to the red being seen, since there are no accompanying processes which cause a rapid decrease in electron number density. Accompanying the spectral changes there are also dramatic changes in the spatial profile of the pulse. These are caused by defocusing due to the gradient in free electron density transverse to the beam direction which may compete with self-focusing due to the non-linear polarisability of the neutral gas. This can manifest itself as the production of multiple foci. The understanding of these phenomena have important consequences in schemes involving intense short laser pulses to produce short wavelength coherent radiation, such as XUV high harmonic generation and X-ray lasers.

We have carried out an experimental investigation into these effects using a 1053nm wavelength Nd:glass laser system based on the technique of chirped pulse amplification which is capable of delivering pulses with energies up to 1J and a minimum duration of ~1ps. The pulses were focused inside a cell containing He, Ne, Ar, or Kr at pressures in the range 10^{-2} mbar to 10 bar. The pulses are recollimated before exiting the cell, are then analysed by a spectrometer and their complete time integrated spectrum recorded by a CCD camera on a single shot basis. The cell has side windows which allow the effects of self-focusing and defocusing to be monitored on the same shot via observation of the plasma self emission.

The spectra show blue shifts which are dependent on the gas species, pressure and laser intensity. There is no noticeable red shifted light indicating that the effect on the spectrum is indeed mainly due to ionisation dynamics and not the non-linear response of the neutral gas. The extent of the blue shifts appear to increase with atomic number of the species, gas pressure and laser intensity and also often show multiple wavelength peaks displaced from the laser central wavelength. The number of these peaks varies according to the particular experimental conditions.

In contrast, when investigating the spatial profile of the pulse under the same conditions, we observe multiple foci through the side windows, which indicates that the non-linear response of the neutral gas is having an effect here along with the creation of electrons due to ionisation, but it is not manifesting itself in the spectra.

As well as the blue shifted fundamental light, there is a considerable amount of 3rd harmonic radiation produced which also shows blue shifts and appreciable spatial structure. The relative magnitudes of the blue shifts on the fundamental and 3rd harmonic should help in understanding at what time in the pulse the harmonic is produced.

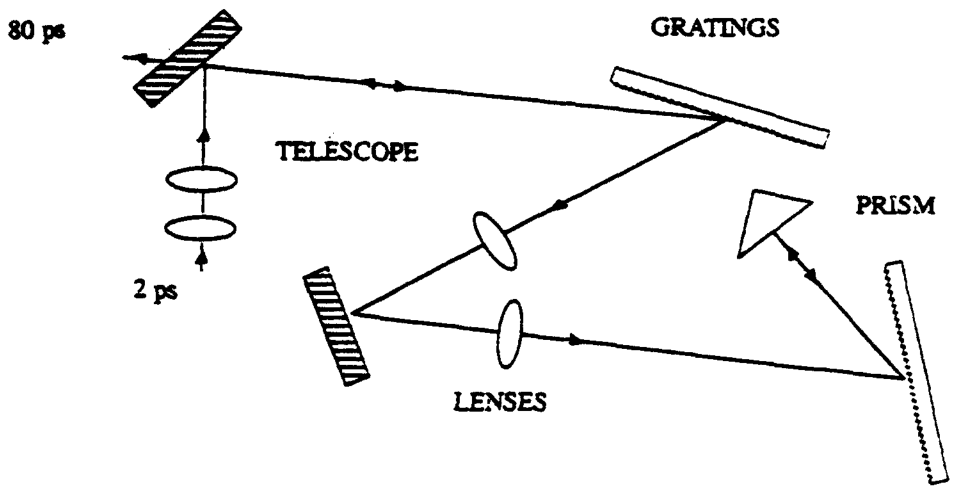

Figure 1. Schematic of the grating stretcher.

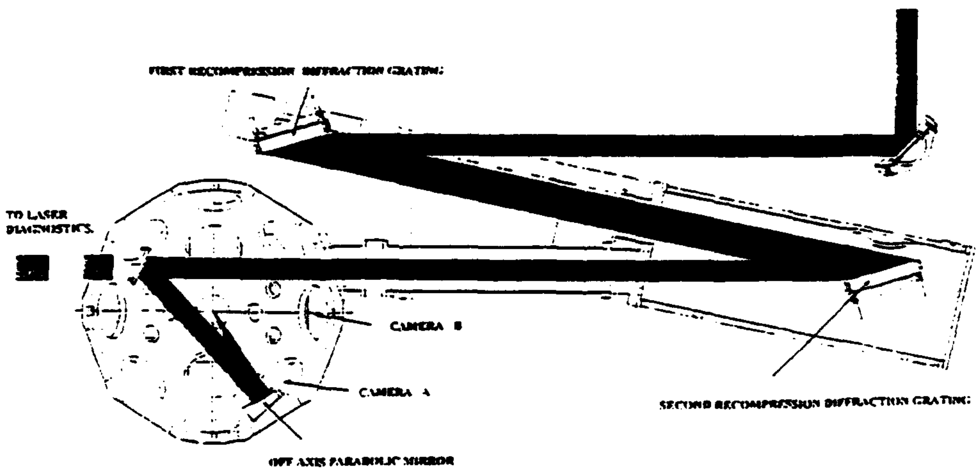

Figure 2. Engineering Drawing of Compression Chamber.

ULTRA-SHORT PULSE AMPLIFICATION EXPERIMENTS ON THE VULCAN GLASS LASER SYSTEM

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A Chirped Pulse Amplification (CPA) mode of operation has been developed on the VULCAN high power Nd:glass laser system, at the Rutherford Appleton Laboratory. The CPA technique enables short pulses to be amplified to high energies in glass laser systems without the onset of nonlinear beam break up. A short pulse is generated, stretched in time, amplified and finally recompressed prior to delivery to the target.
An Additive Pulse Modelocked (APM)[1,2] oscillator was developed for this work, giving 2 ps pulses. The pulse was stretched to ~ 80ps using a double passed grating pair (figure 1). The gratings introduce a frequency dependent time delay, producing a pulse with a linear frequency sweep (chirp). The stretched pulse was then amplified in one beam line of the VULCAN laser.
The amplified pulse was propagated to one of the VULCAN target areas and re-compressed using a single pass of a pair of large aperture diffraction gratings. The intensity contrast ratio of the background of the pulse to its peak was better than 5×10^5, measured by a novel third order cross-correlator[3].
The maximum power on target was 8 TW, in a 19 J pulse, with a re-compressed pulse duration of 2.4 ps. The beam was focused by an off-axis parabola onto target as shown in figure 2. The far-field intensity distribution of the recompressed pulse was 5-10 x the diffraction limit, giving an intensity on target of $\sim 4 \times 10^{17}$ Wcm^{-2}.
A series of laser interaction experiments have been performed using the new CPA facility. These include laser/solid interaction and multi-photon ionisation studies in low pressure gasses.

ACKNOWLEDGEMENTS
The authors are pleased to acknowledge the valuable assistance of the Optoelectronics Research Centre at Southampton University in the construction of the oscillator.

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TWO DIMENSIONAL MODELLING OF RAMAN CONVERSION.

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The final Raman conversion stage of the Sprite laser system at the Rutherford Appleton Laboratory plays a crucial role in the amplification of UV pulses to high intensities. A number of pump beams from the Sprite KrF amplifier propagate at small angles to the axis in a 1 metre light guide where they interact with a Stokes wave travelling directly down the axis. One of the merits of this arrangement is that although the spatial coherence of the pump beams is only moderate, the coherence of the amplified Stokes beam is high. This arises from the insensitivity of the Stokes gain to the phase of the pump wave (at least on a slow time scale). The real situation is more complex, however, because the relaxation time of the Raman medium (methane) is about 28 ps and with pulses in the region of 10 ps, the system clearly operates in the transient regime.

A detailed three-dimensional simulation of the angled beam geometry including their wall reflections would require an impractically complex computer code. On the other hand, useful results have been achieved in the past with a one-dimensional model [1-2] in which the pump and Stokes waves propagate at different speeds. This approach offers a crude first-order representation of the effective velocity dispersion associated with the angled beams.

In this paper, we present the first results from a new two-dimensional code that takes full account of the angular behaviour and wall reflections of two beams, but is of course restricted to beams travelling in a plane. The code relies on two tiers of interpolation to mimic the effect of non-collinear propagation and an implicit finite difference method to improve convergence properties. It enables far more detailed and reliable simulations of the real laboratory situation to be undertaken and provides a greatly enhanced aid for experimentalists seeking to optimise the performance of this unique laser system. In addition to investigating the effect of angular dispersion, we also examine the role of noise in the Raman conversion process. Simulations are made with both noisy and chirped pulses in an attempt to predict the results of future experiments.

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KINETIC AND OPTICAL PROPERTIES OF CONDENSED MATTER INTERACTING WITH ULTRA-SHORT, ULTRA-STRONG LASER PULSES

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A survey of recent results on the kinetic and opt.cal properties of matter exposed to ultra-short, ultra-strong laser pulses is presented. Under such conditions plasmas with T(e) > > T(i) can be created. 1. It has been shown that if T(e) > > T(i) electron-electron interaction is determined by ion sound wave absorption and emission and the kinetic equation for electrons in a two component plasma can be solved analytically. 2. A theory of electron-ion energy exchange in an ultra-strong laser field has been developed. 3. The electron kinetic equation for a strongly coupled plasma in an intense laser field has been analytically solved for arbitrary strength of laser field. An analytical solution for the non-linear current of first and higher order harmonics has been found.

HIGH BRIGHTNESS KrF LASER USING CHIRPED PULSE AMPLIFICATION

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The highest power is achieved from a laser system by extracting all the stored energy in pulses of duration limited by the gain bandwidth of the laser medium. A Chirped Pulse Amplification (CPA) technique is necessary for efficient amplification of the shortest pulses (approximately 100 fs) in KrF large aperture amplifiers in order to overcome the power limit imposed by nonlinear processes. In the SPRITE KrF laser it is necessary for 100 fs input pulses to be stretched to approximately 10 ps to allow amplification to several times the saturation fluence ($E_{sat} = 2$ mJ/cm^2). The modest requirement on stretch factor allows reasonable tolerances on mechanical and beam defects. Of particular concern in KrF as opposed to solid state lasers is the effect of strong gain saturation. Theoretical modelling of the effect of saturated amplification of the chirped pulse on the recompressed pulse profile indicates an essentially unchanged pulse duration at FWHM with an increase of only a factor 1.65 in pulse width at the 10^{-7} level.

In initial experiments we have demonstrated CPA and recompression to 150 fs at 249 nm using a distributed feedback dye laser oscillator and a discharge pumped KrF amplifier (1). Comparative spectral measurement of pulses both directly amplified and amplified by CPA showed that there was large spectral profile distortion for amplification of chirped pulses thus demonstrating the presence of this strong saturation. Despite this, the recompressed pulse duration was close to the transform limit.

On the SPRITE KrF laser sub 100 fs pulses are amplified using dye and titanium sapphire amplifiers before frequency tripling to 249 nm and injection into the KrF amplifier system. Modelling of the SPRITE system with the inclusion of a grating pulse stretcher before KrF amplification together with a grating compressor prior to target focusing indicate a capability of 1 Joule in 100 fs on target with a prepulse amplified spontaneous emission intensity of $< 10^9$ W/cm^2. Details of the system design along with measurements of all aspects of system performance will be presented.

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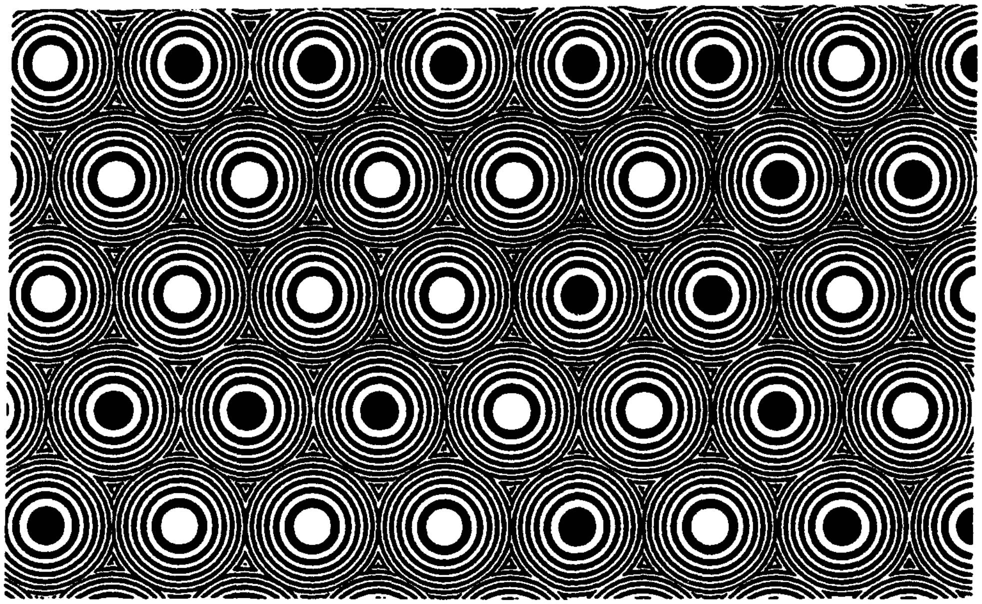

FIGURE 1. BINARY ZONE PHASE PLATE - PHASE MASK PATTERN

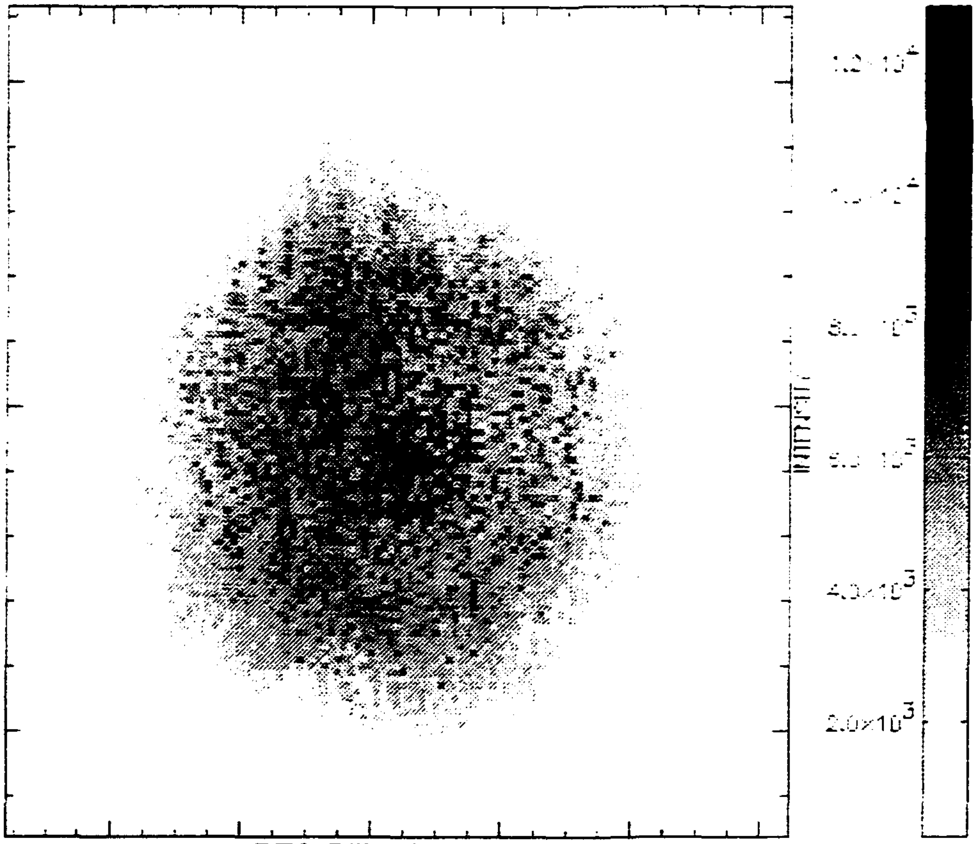

FIGURE 2 BINARY ZONE PHASE PLATE - OPTICAL IMAGE

Focal Intensity Smoothing In The Optical & X-Ray Domains Using A Binary Phase Zone Plate Array

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The generation of a uniform focal intensity profile is important in high power laser systems used for laser plasma interaction studies and inertial confinement fusion research. We report on a technique utilizing a binary diffractive focusing element to produce uniform intensity optical and x-ray profiles with a 0.5TW laser system

The random phase plate was developed by Kato et al(1) to scramble the phase of the beam with the resulting improvement in the intensity profile due to the superposition of many small beamlets. This technique although inefficient at producing uniform intensity profiles has been practiced at several laboratories using different techniques. Deng et al (2) have extended the work by using an array of refracting lenses instead of phase variations to provide uniform illumination more effectively.

We report on the development and use of a novel binary phase plate to generate a flat top intensity distribution from a non-uniform input beam produced by a high power laser. This technique uses a principal focussing lens followed by a hexagonally packed, phase zone plate array. The phase zone plate is fabricated by conventional photo-lithographic techniques to give phase delays of 0 or π radians in the even or odd orders of the zone plates (Figure 1).The focal lengths of the zones are also randomised by +/- 1% in order to enhance the smoothing. The uniform intensity profile is a result of the overlapping images produced by de-focusing the lens/phase plate combination. It has been shown that this technique is largely independent of the spatial profile of the incident beam.

Optical (526nm) (Figure 2) and x-ray images (2.5 kev) of the intensity distribution have been produced utilizing this technique on a 0.5TW laser system. The x-ray images were obtained by firing the laser at a flat gold target.

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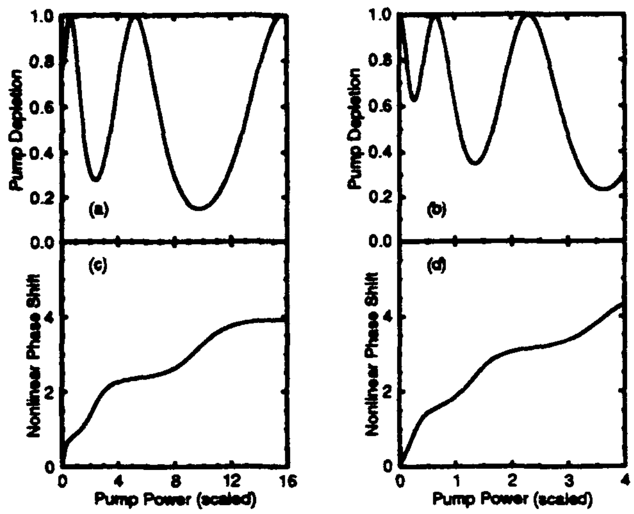

Fig. 1. Response of the cascaded second order nonlinearity. (a) shows the pump depletion for a phase mis-match $\Delta kL=\pi$, (b) the pump depletion for $\Delta kL=2\pi$, (c) the induced nonlinear phase change for $\Delta kL=\pi$, and (d) the nonlinear phase change for $\Delta kL=2\pi$.

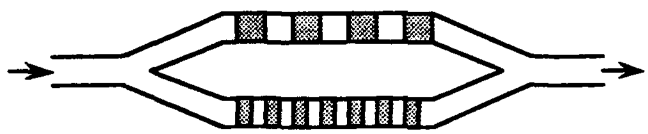

Fig. 2. Schematic of the cascaded second order push-pull all-optical switch. Each arm of the interferometer has a grating of a different period designed to give an opposite phase mis-match and hence opposite nonlinear phase shifts.

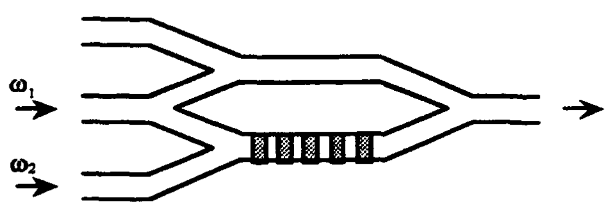

Fig. 3. Schematic of a Mach-Zehnder dual input all-optical switch for a cascaded second order nonlinearity. A grating is placed on the arm where both inputs will be present to select the appropriate phase mis-match.

All-Optical Switching Using a Cascaded Second Order Nonlinearity in Semiconductor Waveguides

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It has recently been shown that an effective ultrafast third order refractive nonlinearity $\chi^{(3)}$ can be obtained by cascading a second order nonlinearity $\chi^{(2)}$ [1,2]. Physically this arises as there is downconversion of the generated second haromonic away from perfect phase matching which is, in general, out of phase with the original fundamental. This nonlinear phase shift is strongly dependent on the phase mis-match and is of opposite sign on either side of perfect phase matching. From the standard coupled differential equations derived from the slowly varying amplitude approximation, the nonlinear phase change can be determined either numerically or analytically (using Jacobi elliptic integrals). This nonlinear phase change is shown in fig. 1 as a function of optical power along with the fundumental depletion for phase mis-match values $\Delta kL=\pi$, 2π.

A schematic of an integrated all-optical switching device to take advantage of this cascaded nonlinearity is shown in fig. 2 [3]. Quasi-phase matching [4], through the use of gratings placed on the waveguide arms, is used to obtain opposite phase matching criteria in each arm and hence opposite nonlinear phase shifts. The cascaded nonlinearity can also be extended to the nondegenerate regime where two inputs are applied, differentiated either in wavelength or polarisation [5]. An alternative device schematic for this dual input mechanism is shown in Fig. 3. Practical estimates for the optical switching power levels in this devices using AlGaAs at optical communication wavelengths are of the order of tens of Watts.

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RELATIVISTIC TREATMENT OF A CLASSICAL HYDROGEN ATOM IN AN ULTRA-STRONG LASER FIELD

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Advances in short pulse laser technology have allowed us to generate super-intense laser fields with peak intensities greatly exceeding the atomic unit of intensity; electrons in such fields have a quiver interaction energy which approaches the rest mass energy of the electron. Current theoretical activity on the stabilization of atoms in super-intense fields has emphasized the role of large quiver amplitudes, but has used entirely non-relativistic methods. In this paper, a relativistic treatment of the dynamics of a classical hydrogen atom in an ultra-intense classical laser field is given. We investigate both single trajectories of the electron and the ensemble averaged distribution via the standard Monte Carlo method. Special emphasis is put on the harmonic spectra which are evaluated by Fourier transforming the acceleration of the electron and on the relativistic features of harmonic generation and ionization suppression. Our method involves the numerical integration of the classical relativistic Lorentz equation for an electron moving in the combined laser and Coulomb fields. We see directly in the evolution of the electronic displacement the effects of the relativistic mass increase. The non-relativistic displacement in very strong fields is the usual ponderomotive excursion to very large values in the oscillatory term. The deviation from pure harmonic motion leads to the generation of harmonics. However, the relativistic displacement is limited by the increased dressed electron mass and evolves in a super-intense field essentially at the speed of light except at the classical turning points, when it rapidly reverses its direction of motion. these reversals are shown to influence strongly the formation of very high harmonics, and the evolution of atomic ionization.

A FINITE DIFFERENCE SIMULATION OF MULTIWAVE MIXING IN PLANAR OPTICAL WAVEGUIDES

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Multiwave mixing (MWM) is the process by which interfering laser beams create and diffract off an induced periodic distribution in refractive index. When a phase difference is present between the intensity distribution and the generated refractive index grating energy exchange between the writing beams is possible and the process is known as Two Wave Mixing. Plane wave theories describing such phenomena are now well established and the physical mechanisms well understood[1]. The higher intensities available in guided wave geometries leads to the conclusion that efficient wave mixing might be obtained in optical waveguides[2]. Such waveguides could be used for optical processing such as switching.

We present the results of a Finite Difference (FD) simulation of MWM suitable for describing interactions in a planar optical waveguide. The method is based on an implicit FD representation of the 2D scalar paraxial wave equation. This necessitates the application of the Effective Index method to a given guide before the FD simulation can be applied. One dimensional beams are then propagated through the nonlinear medium to a given output plane. The resulting field distribution is then Fourier Transformed to produce a spectral angular distribution. This will reveal the presence of the input beams and any generated diffracted orders. The relative heights of the spectral peaks directly gives the diffraction efficiencies.

The FD methodology has a number of advantages: The input beam profiles may be of arbitrary and finite dimensions (typically in a waveguide diffraction will take place off a grating containing only ten or so periods). The method will also automatically account for all the higher order beams present. It is possible, by an inverse Fourier Transformation, to assess the effects of the nonlinear propagation on the individual beam sizes. The FD simulation has also been used to model the influence of a quasi-phase matching grating to resonantly enhance the generation of higher order beams. Nearly degenerate wave mixing can also be modelled by the inclusion of a complex nonlinear index which will account for the phase difference induced by the motion of the resulting grating. A functional dependence of the absorption on the local intensity can be included in a straightforward manner.

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FREQUENCY DOUBLING OF CO_2 LASER WAVELENGTHS INTO THE MID-INFRARED

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Frequency doubling [1] at CO_2 laser wavelengths (9-11μm) offers a potentially useful source of mid-infrared laser radiation. A variety of non-linear materials ($AgGaSe_2$, $AgGaS_2$, Tl_3AsSe_3, $ZnGeP_2$, GaSe, etc...) have a high figure of merit for CO_2 laser frequency doubling and transmit over the required range [2]. Over recent years advances in crystal growth techniques have enabled crystals of longer length to be grown with reduced absorption losses and increased damage thresholds. These have resulted in reported peak conversion efficiencies of up to 60% [3].

We have performed single shot conversion efficiency measurements on a selection of non-linear materials of differing lengths for various pump pulse powers, energies and focussing geometries. An assessment of crystal quality has been made by analysing tuning curve profiles and damage thresholds and effective non-linear optical coefficients have been measured for $AgGaSe_2$. We have developed a theoretical model based on the plane wave solution to the coupled wave equations given by Yariv, incorporating pump and harmonic depletion assuming phase match conditions are maintained. This is in good agreement with experimental results and predicts optimum crystal properties and experimental configurations for maximum conversion efficiency.

Second harmonic generation in $AgGaSe_2$ at kHz repetition rates has also been studied using low incident pulse intensities and mean powers of up to 2 Watts. At present further mean power studies are being undertaken at 100Hz repetition rates using higher incident pulse energies and intensities to investigate the potential problems of thermal loading and its effect on frequency doubling performance.

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OPTICAL NONLINEARITIES IN DYES AND LIQUID CRYSTALS

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Dyes and liquid crystals form an important set of nonlinear optical materials which combine the sensitivity and speed for the control and switching of pulsed laser beams. The paper will examine the mechanisms of the absorptive and refractive nonlinearities displayed by these media, and will describe studies at Malvern to understand and quantify these effcts using a range of diagnostic techniques.

Liquid crystals have been under study as switch media for some years; the trade-offs which control the switching that can be achieved using the optical Kerr effect will be described and the performance of some advanced materials will be presented. Results will also be presented showing nonlinear absorption by phtalocyanine and other dyes. Inducible absorption and saturable absorption can both be displayed in the same material, and the processes which control these competing effects will be discussed.

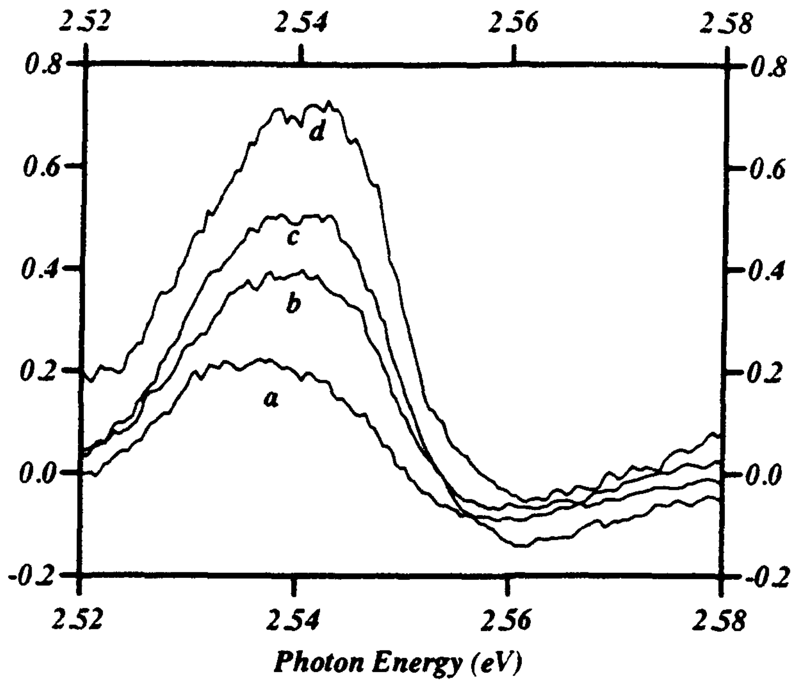

Figure 1. Differential transmission spectrum measured for different excitation irradiances : a) 100 kW/cm^2, b) 300 kW/cm^2, c) 500 kW/cm^2, d) 1 MW/cm^2

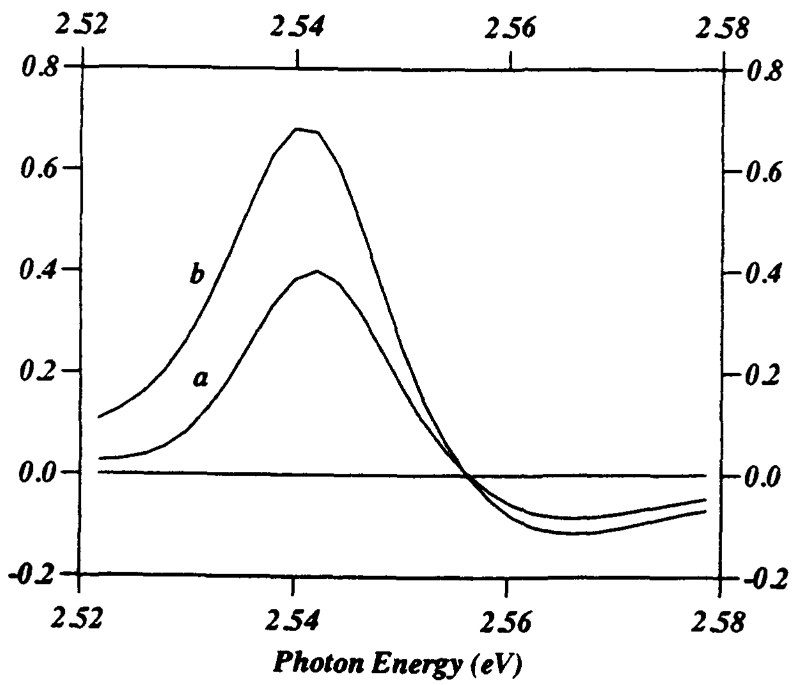

Figure 2. Differential transmission spectrum calculated for two free-carrier density levels : a) 3.3x10^{17} cm^{-3}, b) 6.7x10^{17} cm^{-3}.

ALL-OPTICAL EXCITONIC NONLINEARITIES IN A ZnSe/(Zn,Cd)Se MULTIPLE QUANTUM WELL MODULATOR STRUCTURE

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Recent advances in wide-gap semiconductor growth technology have paved the way to the first diode lasers (1,2) and the prospect of electro-optic devices operating in the blue and blue-green spectral region.
The absorption edge in II-VI semiconductors exhibits prominent excitonic features due to the high exciton binding energy (22 meV in bulk ZnSe), which is enhanced further in low-dimensional structures i.e. in quantum wells. As in III-V semiconductors, self electro-optic effect devices (SEED's) based on the quantum confined Stark effect (QCSE) at the exciton absorption peak are likely candidates for optically bistable switches (3). This underlines the importance of understanding and characterising the nonlinearities associated with the exciton states.
Bleaching of the exciton absorption peak in a p-i-n QCSE modulator, consisting of a $ZnSe/(Zn_{0.8},Cd_{0.2})Se$ MQW structure within a ZnSe p-n junction (4), was investigated at both 77 K and 300 K. A nondegenerate excite-probe experiment of unconventional design was used: the photo-excitation was generated by a 2 ns pulse, originating from an excimer-pumped dye laser, with Coumarin 47 in its oscillator dye circuit and Coumarin 102 in its amplifier stages, for the low temperature measurements. Coumarin 102 and 307 were used for the room temperature experiments. The respective excitation wavelengths were 462 nm and 484 nm, with photon energies well above the exciton peak at each temperature. These combinations of dyes resulted in a large amount of the excimer pump radiation being converted into amplified spontaneous emission (ASE) rather than into laser light. The laser emission and the ASE were then separated using a holographic grating and used as temporally coincident excite and probe beams, respectively. The pulse duration of both beams was much longer than the recombination time in the material, so that the excitation was quasi-cw.
Figure 1. shows the differential increase in transmission around the exciton wavelength at 77 K, for several pump irradiance levels. Both position and broadening of the bleaching match the corresponding characteristics of the heavy-hole exciton obtained from the linear absorption spectrum. Theoretical curves for two different free-carrier densities were obtained from a solution of the Bethe-Salpeter equation, using the single plasmon pole approximation for the dielectric function (5). Good qualitative agreement is found (figure 2.) allowing an estimate of the free-carrier lifetime to be made : 7 ps for $6.7x10^{17}$ cm^{-3} (1 MW/cm^2 excitation irradiance) and 11 ps for $3.3x10^{17}$ cm^{-3} (300 kW/cm^2).
Room temperature measurements have also been carried out and show a similar bleaching of the heavy-hole exciton resonance.
Careful examination of figure 1. shows a slight shift to higher energies of the experimental differential transmission peak, which is not reflected in the calculations. The origin of this remains to be explored.
The p-i-n structure enables the influence of an electric field on the above nonlinearity to be studied; the results of which will be discussed.

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OPTICAL BISTABILITY AND X-SHAPED HYSTERESIS IN LASER DIODE AMPLIFIERS

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Laser diode Fabry-Perot amplifiers exhibit good performance characteristics when used as bistable devices, with very low switching energy and the benefits of optical gain. Their operation in transmission has been well studied and the behavior can be explained by gain saturation effects. Less attention has been given to the reflection mode of operation.

The device used in these experiments was a Fabry-Perot Channelled Substrate Planar Large Optical Cavity (CSP-LOC) Double Heterostructure GaAs laser diode. It had a high reflectivity coating on one facet with the other facet as cleaved. This asymmetry makes the device particularly suitable for operation in reflection. We report the first observation of previously predicted bistable effects in reflection, including a transition from the normal anticlockwise hysteresis to a clockwise hysteresis more typical of passive devices. This transition occurs via an intermediate X-shaped hysteresis in the light intensity input-output curves and can be caused by altering the device bias or the detuning of the incident light from the cavity resonance position. A similar transition can be observed in the resonance profile if the bias is altered or the incident power changed.

The transmitted and reflected signals were monitored simultaneously and the bistable phenomena compared. Our results are in good qualitative agreement with theoretical predictions from the accepted theory of bistability in laser diode amplifiers.

REDUCTION OF SATURATION CARRIER DENSITY IN A COMPRESSIVELY STRAINED ASYMMETRIC FABRY-PEROT MODULATOR.

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Many strained optical devices such as diode lasers and modulators, exploiting both electro-optic and all-optical nonlinearities , have been demonstrated with InGaAs as the active layer grown on GaAs. These devices have very good operating characteristics, despite the considerable lattice mismatch inherent in their growth. It is widely believed that some of the advantageous characteristics, such as reduced thresholds in strained lasers, are due to the modification of the valence band structure. Any change in the dispersion of the valence band will alter the density of states and also the operation of any strained non-linear device dependent on optically generated carriers. In a compressively strained material, such as InGaAs on GaAs, the change in the valence band should result in a reduction of the carrier density necessary for absorption saturation. However practical devices, with necessarily thick structures of many periods of quantum wells, may suffer from strain relaxation with a resultant loss of advantage over unstrained materials.

In this paper we present the results of an investigation into the non-linear saturation characteristics of the band edge absorption in a strained normally-off all-optical asymmetric Fabry-Perot modulator (AFPM) [1], with 29.5 $In_{0.1}Ga_{0.9}As/GaAs$ multiple quantum wells. The AFPM achieves good reflectivity modulation of 60%, with a contrast ratio of 12.2:1 and a low insertion loss of 1.87dB. By measuring the carrier lifetime in the material [2], through pump-probe measurements, and the intensity dependent absorption, we have calculated the saturation carrier density to be 3.1×10^{17} cm^{-3}. This density is a factor of about 2.5 less than the saturation density in a similar unstraiuend GaAs device. Therefore the improvement in saturation characteristics expected in compressively strained InGaAs/GaAs is preserved in the thicker structures necessary for a useful device.

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CONTRASTING ROUTES FOR SUM FREQUENCY MIXING IN SODIUM VAPOUR

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Single frequency continuous wave lasers have been used for a high resolution study of two contrasting routes for magnetic field induced sum frequency mixing in sodium vapour. The routes differ in the placing of the quadrupole transition, the 3S-3P-3D route having a quadrupole allowed return transition (dipole-dipole-quadrupole) and the 3S-3P-4P route being dipole disallowed on the 3P-4P transition (dipole-quadrupole-dipole). Close single and two-photon resonant enhancements were used to produce a high single pass conversion efficiency in the three wave mixing processes.

The former route utilises strong transition matrix elements leading to highly efficient mixing[1], indeed to our knowledge conversion efficiencies are the highest observed for a magnetic field induced cw process in vapours. Line profiles showing the various Zeeman components will be displayed and the conditions for maximum conversion efficiency detailed. Furthermore, by tuning the fundamental input wave across the 3P levels of sodium a wide choice in phase matching conditions, including both positive and negative values, could be achieved. A detailed study of the phase matching variation with particle density was undertaken including the effects of focusing. The spatial characteristics of the output beam were observed and rings observed due to the different confocal parameters in the input waves.

In contrast the phase matching conditions for dipole-quadrupole-dipole route were dominated by the return transition and thus changed during tuning across the Zeeman sub-levels producing distortions in the observed lineshapes. Linear re-absorption of the generated sum frequency wave reduced output levels compared to the previous route.

A numerical model of various three level systems appropriate to the above studies has been developed and the use of electromagnetically induced transparency[2] investigated analytically and numerically in this context. At the present the main limitation on conversion in the former route is the parasitic linear absorption of a fundamental input wave which can be substantially reduced by this coherent effect. An appreciation of the novel mechanism and experimental conditions required will be presented along with predictions of an enhancement of two orders of magnitude due to the sum frequency susceptibility not being similarly reduced under Doppler broadened conditions.

A comprehensive investigation of these highly efficient second order processes will be presented along with novel proposals for further efficiency improvement in the first and other similar wave mixing processes.

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NONLINEAR OPTICAL PROPERTIES OF A SOLUBLE FORM OF POLYISOTHIONAPHTHENE

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Abstract

The third order nonlinearity of a low bandgap conjugated organic polymer has been assessed. Degenerate four-wave mixing experiments (at 1.064 μm using picosecond pulses from a passively mode-locked Nd:YAG laser) on solutions of the polymer have permitted the determination of the microscopic third order nonlinearity (γ). The polymer exhibits unusual behaviour which is solution concentration dependent. This behaviour is thought to be due to aggregation effects and strongly suggests that the bulk response of the material is remarkably large, the third order nonlinearity being of the order of ten times greater than the polydiacetylenes.

Following these preliminary studies, a sample of the same polymer with a greater average molecular weight was also measured and was found to possess an even larger third order nonlinearity. This is thought to be due to an increased excited state dipole moment arising from a greater delocalisation of the carbon π-electron system.

VIOLATION OF BELL'S INEQUALITY AND SINGLE PARTICLES

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Bell's inequality has provided the means to test the consistency of fundamental ideas of reality and locality with experiment. The celebrated experiments of Aspect and co-workers have left us with little doubt that Bell's inequality *can* be violated leading to the conclusion that we cannot incorporate *both* reality and locality within quantum physics. However, violation of Bell's inequality can tell us much about non-classical correlations even for systems where it is *difficult* to establish violation of local realism. We show here that correlated particles are *not necessary* to violate the mathematical relationship which constitutes the "Bell inequality" and that violations can be observed with *single* particles. The interpretation of the violation, in this single-system case, can not be phrased in terms of a failure of local realism but is rather a feature of quantum complementarity.

We show that a simple physical system consisting of two atoms successively interacting with a micromaser cavity can develop strong non-local correlations and violate a Bell inequality in the spirit of Bell's original analysis. The first atom develops a strong correlation with the field mode in the cavity through its strong resonant interaction. The second atom enters the cavity, interacts with the field and thereby becomes entangled with the first atom. However, we also show that violation of this inequality for the two atoms *does not depend on whether the second atom enters the cavity before* measurements on the first atom have been performed. The two atoms will display violations of the Bell inequality *irrespective* of when measurements on the first atom are performed. Within this single physical system we interpret one violation, when measurements are performed *after both* atoms have interacted with the cavity, as due to the failure of local realism; the other violation, when the first atom is measured *prior* to the second entering the cavity, we interpret as due to quantum complementarity.

Analysis of the micromaser system shows that the two atoms need never have interacted with the *same* cavity in order for a violation of the Bell inequality to be observed. This in turn suggests that similar violations can be observed in single particles. We choose three observables, such as spin in 3 directions, and prepare a particle in an eigenstate of one of these observables, chosen randomly. The choice is recorded. The particle is then transmitted to a measuring device which, randomly and independently of the state preparation, measures one of these three observables. We show that the correlations between the preparation data and the measurement data will violate a suitably-constructed Bell inequality. This has important implications for the design of quantum cryptography systems in that the production and manipulation of *correlated* particles is *not necessary* to achieve security using a Bell inequality protocol.

THE ATOMIC AHARONOV-CASHER EFFECT

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In 1984, Aharonov and Casher predicted that a magnetic dipole μ cycled around a line of electric charges would acquire a phase shift [1]

$$\Delta\Phi_{AC} = \oint \frac{(\mu \times E) \cdot dr}{\hbar c^2} = \frac{\mu\lambda}{\hbar c^2 \varepsilon_0}$$

where μ is perpendicular to the electric field **E** and parallel to the wire. This phase shift depends only on the magnetic moment and the charge per unit length λ and is analogous to the well-known Aharonov-Bohm effect in which the phase associated with an electron depends on the electromagnetic potential in which it moves [2]. The Aharonov-Casher phase shift has been measured by neutron interferometry [3]. The observed shift was 2.19 ± 0.52 *mrad* which was in approximate agreement with the theoretical prediction of 1.50 *mrad*. We describe a version of the Aharonov-Casher effect suitable for observation with atoms. This is a significantly larger effect as the atomic magnetic moment is typically three orders or magnitude larger than that of the neutron ($\mu_B \approx 2 \cdot 10^3 \mu_N$).

It has been suggested to use atom interferometry in a similar geometry for measuring this effect [4]. However, the opening angle in an atom interferometer is typically very small and it is important that the two parts of the atomic wave function travelling on either side of the wire do not have opposite magnetic moments. This would be the case if the wave function was symmetrically distributed over magnetic sublevels [5] or split between J=1/2 ground-state hyperfine levels [4]. Both these difficulties can be resolved if the electric field from the wire is replaced by a uniform field. As the two parts of the atomic wave function with opposite magnetic moments pass through the same field they will acquire a phase difference

$$\Delta\Phi = \frac{2\mu E \ell}{\hbar c^2}$$

where ℓ is the effective length of the region of the electric field. For realistic experimental parameters this shift can be on the order of 10°.

It is interesting to consider this experiment from relativistic point of view. The electric field gives rise to a motional magnetic field which Zeeman shifts the atomic levels. This shift integrated over the time (in the atom's rest frame) it takes to pass through the electric field yields the same phase shift $\Delta\Phi$. Thus we have shown that the Aharonov-Casher effect is identical to the motionally induced Zeemen effect. As it is independent of velocity it is a relativistic effect of order zero in velocity.

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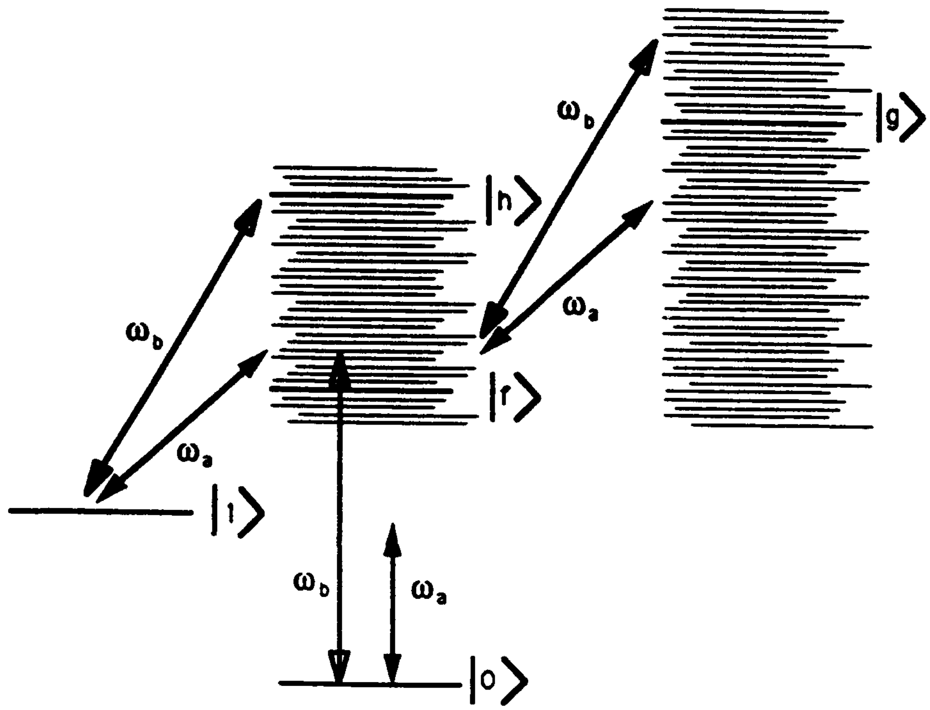

Figure 1 Simplified atomic-level scheme, showing basic LICS system of initial atomic state $|\,0\,\rangle$ coupled by lasers **a**, **b** to atomic continuum states $|\,f\,\rangle$ to which a second bound state $|\,1\,\rangle$ is coupled due to lasers **a**, **b**. A second continuum $|g\,\rangle$ is coupled to the first via lasers **a**, **b**. The frequencies are such that $\omega_0+\omega_b$ is approximately $\omega_1+\omega_a$. Near threshold photoelectrons are ejected with energies near $|\,f\,\rangle$, those with energies near $|\,g\,\rangle$ would be due to ATI processes.

LASER INDUCED CONTINUUM STRUCTURES (LICS) AND ABOVE THRESHOLD IONISATION (ATI)

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LICS [1] can be produced by embedding a bound atomic state into an atomic continuum via a strong laser field. Such features can be probed from a second bound state with another weak (or strong) laser. Quantum interference effects lead to depletions and enhancements in the ionisation rate near zero two-photon detuning. For the weak probe case an asymmetric Fano profile is predicted, which has been reported in recent experiments [2]. For the strong probe case a more symmetric and shallower coherence hole is predicted. Observations of LICS via other experiments (harmonic generation, polarisation rotation,..) and theoretical studies on LICS have been recently reviewed [3].

A second atomic continuum can also be coupled to the first via the embedding or (strong)probe lasers (Fig 1). Processes via the second continuum alter the quantum interferences, affecting the LICS ionisation profiles [4]. Such couplings are also associated with ATI [5], electrons absorbing extra photons from the lasers before ionisation. The present work studies the converse effect of the presence of the embedded bound state on the ATI rates, as processes additional to those for single bound state ATI should give interference effects.

A two colour ATI model [6] is extended to determine the photoelectron spectrum. Bound-continuum and continuum-continuum dipole matrix elements are broad-band, the latter depending on energy difference. The RWA applies to the former couplings and continuum thresholds are taken to - infinity. Markovian, damped Schrodinger equations apply as before [4] for the bound state amplitudes, albeit with special shift and Fano q. The photoelectron spectrum is numerically studied for a simple c-c model in the near-zero two-photon detuning regime.

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GENERATING AND DETECTING NON-CLASSICAL FIELD STATES BY CONDITIONAL MEASUREMENTS

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A simple scheme is presented which allows the generation and detection of nonclassical states of the electromagnetic field with *controllable* (predetermined) photon-number and phase distributions. It is based on the two-photon resonant interaction of a single electromagnetic field mode in a high-Q cavity with atoms crossing the cavity sequentially (one at a time) [1,2]. The sequence duration should be much shorter than the cavity-mode lifetime. Nonclassical states of the field are generated conditionally, by selecting only those sequences wherein each atom is measured to be in a desired state after the interaction. The field distribution resulting from a sequence of N selected measurements of the excited state is peaked about $2N$ positions in the phase plane, which evolve sinusoidally as a function of the atomic transit times and are therefore simply controlled [3]. When these peaks are chosen not to overlap, the field state constitutes a generalized Schrödinger "cat"-state. On the other hand if they do overlap, we can make parts of the field distribution strongly interfere, giving rise to a decimation of the photon number distribution. In particular, this process can prepare Fock states with *controlled* photon numbers. The generated phase distribution can be detected by monitoring the pattern of revivals in the excitation of a "probe" atom. We hope to present results that show the effect of different selection strategies.

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QUANTUM PHASE DISTRIBUTIONS AND QUASI-PROBABILITIES

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We present a comparison of two distinct approaches to phase in quantum optics. One approach is the established Pegg-Barnett phase formalism which is based on a Hermitian phase operator expressed in a finite basis [1]. The other approach is based on the use of the Wigner quasi-probability function. We can integrate the function over a radial "wedge" in phase space to define a phase distribution [2,3]. At first sight the Wigner type of phase distribution seems unrelated to the Pegg-Barnett phase distribution. However, in Ref.[3] we showed that given a density matrix ρ, both types of phase distribution can be expressed in the form:

$$P(\theta) = \frac{1}{2\pi}\left[\sum_{m,n=0}^{\infty} \rho_{mn}\, e^{-i(m-n)\theta}\, F(m,n)\right].$$

In the case of the Pegg-Barnett phase distribution the factors $F(m,n)$ are all equal to unity, whereas for the Wigner phase distribution they are given by gamma functions [3]. However, for $m \sim n$ the Wigner $F(m,n)$ are also close to unity and it is found that, e.g. for coherent states with sufficiently large amplitude, the Pegg-Barnett phase distribution is close to the Wigner phase distribution.

The Wigner function is known to exhibit small negative regions; this is a feature which distinguishes it from classical probability distributions. The question arises as to whether or not this negativity can survive in the phase distribution when we perform an integration over the "wedge". We show that this can happen for superpositions containing even Fock states, and that it will never happen for a superposition of only odd Fock states. We will also show that this feature of negativity can be found in the "even coherent states"; i.e. in superpositions of two coherent states such that only even Fock states are found. The squeezed vacuum state also contains only even Fock states, but like the odd coherent states it never shows any negativity in its Wigner phase distribution.

We also show that field states with negative regions of the Wigner phase distribution can be produced by the interaction of a two-level atom with a cavity field. This could be a practical scheme based on the micromaser. The negativity is seen to be fragile and easily destroyed by the presence of cavity dissipation. (A feature shared by the purity of the state; a coherent superposition is also rapidly converted to a statistical mixture.)

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STOCHASTIC SIMULATIONS OF DISSIPATION IN QUANTUM OPTICS

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We have performed calculations of dissipative processes in quantum optics by using two new, and quite different, simulation methods; the state vector Monte-Carlo [1,2] and quantum state diffusion [3] methods. Both of these approaches simulate the evolution of a state vector $|\psi\rangle$ in ways that cannot be completely predetermined because of the use of random variables. Then the properties that one is interested in have to be averaged over many simulations in order to produce meaningful results. A disadvantage of these methods is that residual fluctuations remain after the averaging process. However, because we simulate a state *vector* and not a density *matrix* the demands on the use of storage space are less in the simulation methods. This can be advantageous in large problems [2].

Our purpose here is to make comparisons of the performance of the methods when they are applied to model quantum optics problems. This may be interesting because the principles underlying the state vector Monte-Carlo approach and quantum state diffusion are quite different. In the former, the state vector ($|\psi\rangle$) evolves smoothly under the influence of an effective Hamiltonian ($H_{eff} = H - i\hbar\hat{X}^\dagger\hat{X}$, where, e.g. for dissipation by two-photon absorption, $\hat{X} = \hat{a}\hat{a}$). This continues until, at a point determined by a random variable, there is a "quantum jump" to a state given by a projection with the operator ($\hat{X}$) governing the dissipation. Thus the smooth coherent evolution is interupted by the jumps.

In quantum state diffusion the evolution of $|\psi\rangle$ is determined by a non-linear stochastic differential equation:

$$|d\psi\rangle = -(i/\hbar)H|\psi\rangle dt \;+\; \left[2\langle\hat{X}^\dagger\rangle\hat{X} - \hat{X}^\dagger\hat{X} - \langle\hat{X}^\dagger\rangle\langle\hat{X}\rangle\right]|\psi\rangle dt + \left[\hat{X} - \langle\hat{X}\rangle\right]|\psi\rangle d\xi$$

where $d\xi$ is a random complex Weiner variable. In consequence the time evolution is not smooth on a very small scale because of the discretised diffusion of the state vector in its Hilbert space. In this way one can normally distinguish the results of the two approaches.

Our work will address the question of the effectiveness of these two approaches to dissipation for a specific problem of two photon absorption where it is known that the dissipation can result in non-trivial non-classical field state evolution. We will present results on the accuracy and numerical efficiency of the two methods decribed above.

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DISSIPATION EFFECTS ON WAVE PACKETS IN LEVEL CROSSINGS

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The time dependent quantum mechanical evolution of molecular and atomic collision processes forms a relevant research field since it has become experimentally possible to probe these processes within the required time resolution. Using laser pulses with durations of the order of femtoseconds one can actually take snapshots of molecular reactions. The processes can be both monitored and controlled using external electromagnetic fields, especially laser light.

An efficient way to model the time evolution of the laser-assisted molecular and collision processes is to study the dynamics of the vibrational wave packets residing on the electronic potential surfaces, which are shifted to cross and simultaneously coupled by the external fields; this is called the curve-crossing picture. We have constructed one-dimensional theoretical models based on this approach and studied them both numerically and using semiclassical methods [1,2,3].

Recently the inclusion of dissipation has become of great interest and results on this will be presented. Especially when considering the heating and loss processes of ultracooled and trapped atoms one can apply the curve-crossing picture of wave packets with spontaneous decay between the potential surfaces. Also in other systems the finite lifetimes of electronic states must sometimes be taken into account.

There are two ways to treat dissipative models. One can use the traditional master equation for the density matrix, or create a statistical ensemble from different state vector Monte Carlo simulations with stochastic elements in time evolution (quantum jumps) [4]. We have compared the two methods by studying an example of a Landau-Zener level crossing case [5]. The agreement is found to be good. Both methods have their numerical advantages when the hardware and accuracy requirements are considered. The spontaneous decay also introduces new qualitative effects into wave packet dynamics, such as penetration into classically forbidden regions, as well as packet acceleration and deceleration.

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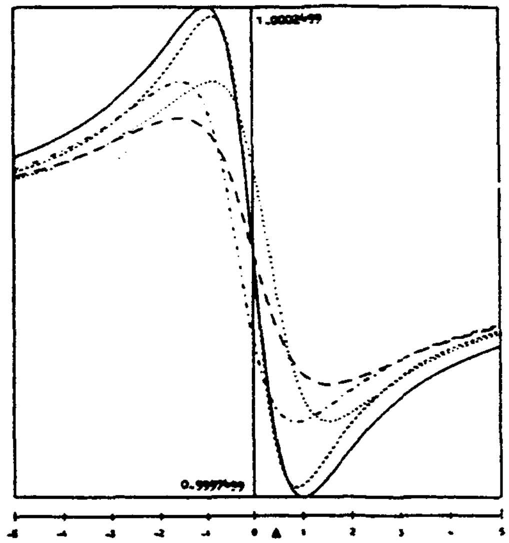

Fig.1 Anomalous dispersion for the normal vacuum $M = N = 0$ and for $|M|^2 = N(N+1)$ for $N = 0.1$ with $\phi = 0, \frac{1}{2}\pi, -\frac{1}{2}\pi$ and π for the squeezed vacuum: $\alpha = 10^{-3}$

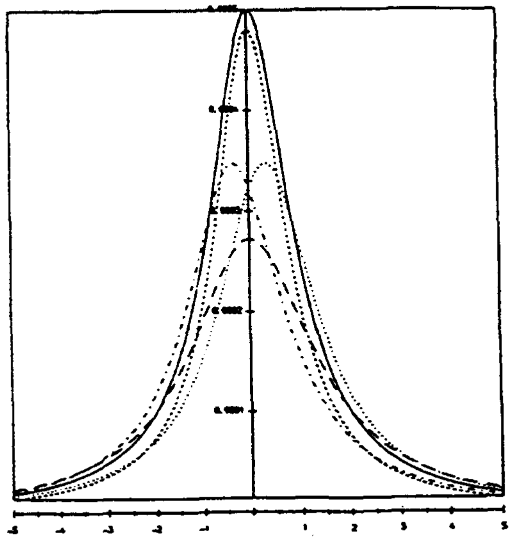

Fig.2 Absorption spectrum against scaled detuning Δ for the normal vacuum $N=0$ and for $n = 0.1$ with $\phi = 0, \frac{1}{2}\pi, -\frac{1}{2}\pi$ and π; $\alpha = 10^{-3}$

LINEAR AND NONLINEAR REFRACTIVE INDICES FOR DIELECTRICS IN SQUEEZED VACUUA

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We have obtained *ab initio* solutions for the nonlinear and linear refractive indices at infra-red or optical frequencies of a dielectric medium occupying a Fabry-Perot cavity in which the dielectric slab of macroscopic width L (the Fabry-Perot cavity) is made up of 2-level atoms bathed in a multimode squeezed vacuum. Starting from a fully quantised Hamiltonian of coupled 2-level atoms and a many-mode quantised electromagnetic field we derive coupled operator Bloch-Maxwell equations in which the quantised electric field operators *e* which drive the atoms are expressed in terms of positive and negative frequency part operator fields $e^{\pm}$ ($e^{+} + e^{-} = e$).

The expectation values of the resultant coupled equations are solved analytically in a *linearising* approximation which corresponds to the case of the quantised linear dielectric in the case when the squeezed vacuum is replaced by the ordinary vacuum. In this linearised theory we find the linear refractive index $m(\omega)$ satisfies the dispersion relation

$$\left[1 + 2N + i\Delta + i\alpha\,\frac{m^2(\omega)+2}{3(m^2(\omega)-1)}\,\frac{1}{1+2N}\right] = |M|e^{i\phi} \qquad (1)$$

where $\alpha = 4\pi n p^2 \hbar^{-1}\gamma^{-1}$, p is a dipole matrix element, 2γ is the A-coefficient, and n the number density of atoms forming the dielectric: $\Delta \equiv (\omega-\omega_o)\gamma^{-1}$ the scaled detuning. The real number N is an occupation number $\langle a^{+}a\rangle$ for the modes of the squeezed vacuum and the complex number M is $\langle aa\rangle$ for these modes. The phase ϕ is an *effective* phase for the complex number M. In fact M has the form $N(x) = M\cos(2k_o z)$ for example, and depends on *position* x inside the dielectric. But the position independent number M emerges in the dispersion relation, equation (1). We show the effect of varying the phase ϕ of the squeezed vacuum on the anomalous dispersion and absorption spectrum in the Figs. 1 & 2 attached. Results for the nonlinear case, and for *optical bistability* in the squeezed vacuum will be reported. Note that equation (1) is the Lorentz-Lorenz relation for $m(\omega)$ when M = N = 0.

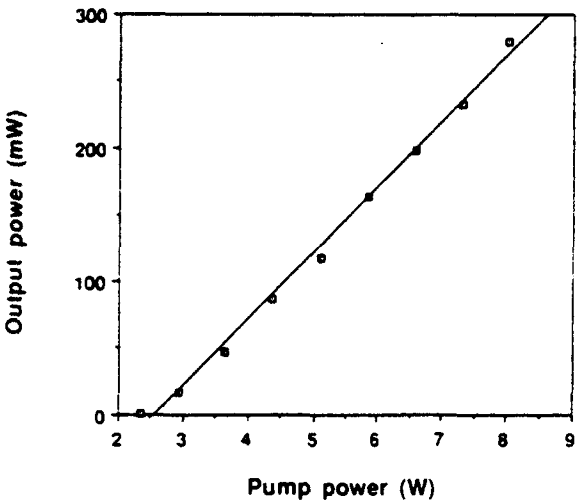

Fig. 1 Variation of output power with wavelength for cw Cr^{4+}:YAG laser

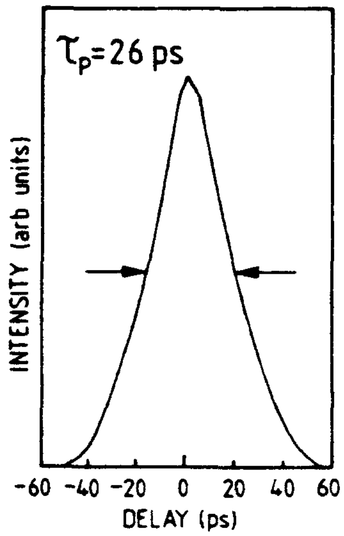

Fig. 2 Autocorrelation trace of the shortest pulses obtained from the actively mode-locked Cr^{4+}:YAG laser

A C.W. MODE-LOCKED Cr^{4+}:YAG LASER

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Femtosecond laser physics has been transformed by the advent of the Titanium-doped sapphire laser. We have successfully applied the novel mode-locking techniques developed to other new laser media including Cr^{3+}:LiSAF which has the potential to be diode-pumped - thus producing a relatively convenient and compact femtosecond laser system. This trend has now been extended to the near infrared spectral region with the generation of femtosecond pulses from Cr^{4+}:Forsterite lasers. We note that the Cr^{4+} ion will extend the spectral coverage of ultrafast solid-state lasers in the region from 1 - 2 μm, in time replacing cryogenic colour-centre lasers. Cr^{4+}:YAG provides gain from 1.34 - 1.56 μm and has been demonstrated as a cw laser at room-temperature, pumped by a Nd:YAG laser in spite of significant excited state absorption [1]. It has an upper state lifetime of ~4 μs and a net peak gain cross-section of ~4 x 10^{-19} cm^2. These parameters are similar to Ti:sapphire and so one may expect that this medium will deliver a similar laser performance. We report here the first mode-locked Cr^{4+}:YAG laser.

The laser crystal used in our experiments was grown at the IRE-POLUS Institute. An astigmatically-compensated cavity configuration, similar to that commonly used with Ti:sapphire lasers, was adopted and the laser was pumped by the 1.064 μm output of a cw Nd:YAG laser. With no output coupling, modulator or tuning element, the laser threshold was as low as 1.6W absorbed pump power. A slope efficiency of ~5% was observed for cw pumping. The laser was tuned from 1.39 - 1.51 μm using a quartz birefringent tuning wedge and the output power with wavelength is shown in figure 1. This tuning range was limited by the dielectric coatings on the cavity mirrors.

Active mode-locking was achieved using a lead molybdate acousto-optic modulator. The RF was applied at ~250 MHz and the laser cavity round-trip time was ~8 ns. When the cavity length was set to the matching point, picosecond pulses at a repetition rate of 125 MHz were observed from 1396 - 1482 nm. Figure 2 shows an autocorrelation trace of the shortest pulses of 26 ps duration (assuming a Gaussian pulse profile) obtained. Typical average output powers ranged up to 20 mW for 8 W pump power. This laser is clearly a candidate for KLM and for APM and should yield femtosecond pulses.

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DEVELOPMENT OF MODE-LOCKED SUB-PICOSECOND ALL SOLID STATE LASERS OPERATING AT 1054 nm

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In this paper we describe the development of sub-picosecond all solid state lasers operating at 1054 nm. These lasers are required as seed sources for the VULCAN Nd:glass amplifier chain at the Rutherford Appleton Laboratory, for chirped pulse amplifier (CPA) experiments. All solid state ie laser diode pumped systems are required for increased compactness, reliability and reduced running costs. The system is also required to produce pulses of energy 0.5 nJ or more.

In order to achieve sub-picosecond pulse durations, the additive-pulse mode-locking (APM) scheme has been adopted. Our experiments to date have concentrated mainly on the $Nd_xLa_{1-x}MgAl_{11}O_{19}$ (LNA, or Nd:LMA) laser. This laser medium can be pumped with commercially available AlGaAs laser diodes, since it has a broad (22 nm) absorption band centred around 800 nm. Furthermore, its fluorescence spectrum exhibits a peak centred at 1054 nm, with a linewidth of 4.4 nm, indicating that pulses as short as 350 fsec should be obtainable from this laser.

The pump source for the LNA laser was a 3 W laser diode array (SDL 2482). Its output was collected and collimated using a combination of a 6.5 mm focal length compound lens and a 15 cm focal length cylindrical lens. The beam was then split into two and the two halves overlapped at a polarizing beamsplitting cube to try to improve the pump beam quality near the focus of the 3.2 cm focusing lens. This significantly improved the laser performance. The active medium was a plane-Brewster rod of LNA (x = 0.09) supplied by LETI, Grenoble, France. The cavity (total length 1.4 m) was completed with a curved turning mirror and a 15% transmission output coupler. A pair of SF10 Brewster angled prisms was inserted in the cavity to provide dispersion compensation. The coupled cavity was formed using various beamsplitters of between 85% and 95% reflectivity to direct a portion of the laser output into a 82 cm length of optical fibre. The coupled cavity was completed with a high reflector mounted on a piezoelectric stack to allow active stabilization of the system. With the correct phase mismatch between the two cavities, mode-locking was readily achieved. Using a 95% reflectivity beamsplitter, pulses as short as 420 fsec were obtained, with average output powers of 18 mW. This corresponds to a pulse energy of 0.17 nJ. Powers as low as 30 mW coupled into the fibre were required for the mode-locking to be self-starting. Using the lower reflectivity beamsplitters, slightly longer pulses (between 500 and 600 fsec) were obtained, with pulse energies up to 0.65 nJ.

Work is also being carried out on a laser diode pumped Nd:glass laser, which could also be used as the seed source for the VULCAN system. Pumping a Nd:glass laser with two 1.2 W broad stripe laser diodes has yielded output powers as high as 520 mW for 10% output coupling. This laser is another good candidate for short pulse generation via the APM technique, and its performance will be reported in detail.

NOVEL EFFECTS IN REVERSE-SATURABLE DYES, WITH THEORETICAL INTERPRETATION TO DETERMINE A COMPREHENSIVE RANGE OF MOLECULAR LIFETIMES .

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Abstract.

Ultrafast nonlinear phenomena for the well known laser dye, HITCI , are investigated using picosecond excite-probe and single pulse transmittance measurements. HITCI is known to display Reverse Saturable Absorption (RSA) at 532nm, in which the transmission drops with increasing fluence for a ps pulse. Several novel effects are observed: From a single pulse transmittance measurement we find that the RSA for increasing input fluences contrary to earlier suppositions is itself reversed [1], leading to absorption recovery and eventually saturation. By fitting the response at high fluences we obtain the relaxational lifetime from the second to the first excited state τ_{12}. In a seperate experiment we employ a weak probe pulse of variable time-delay with respect to the pump to monitor the recovery of the nonlinear transmission, in the RSA regime. This allows us to determine the first interband excited lifetime τ_{01}. Furthermore, due to the unexpected result of further induced absorption after zero delay, which is explained, eventual recovery on a ps timescale enables us to ascertain for the first time - the unusual lifetime τ_{02}, which is found to be approximately double τ_{12}. Optical induced molecular alignment is investigated by varying the polarization of the probe relative to the pump pulse. This shows the anisotropy of the molecule, from which, we are able to deduce the rotational diffusion time. Finally, we observe the intriguing effect of impulsive stimulated Raman scattering [2], this involves the apparent light interaction with an excited coherent phonon which is modelled to uniquely resolve both the natural frequency and dephasing time of the fundamental vibrational mode. Extended theoretical analysis accounting for the aforementioned processes enpowers us to produce computational fits and explanations for all the picosecond responses. These observations, and their interpretation, have profound consequences for obtaining the direct time-resolved dynamics of any molecule. at any wavelength where the dye shows induced absorption.

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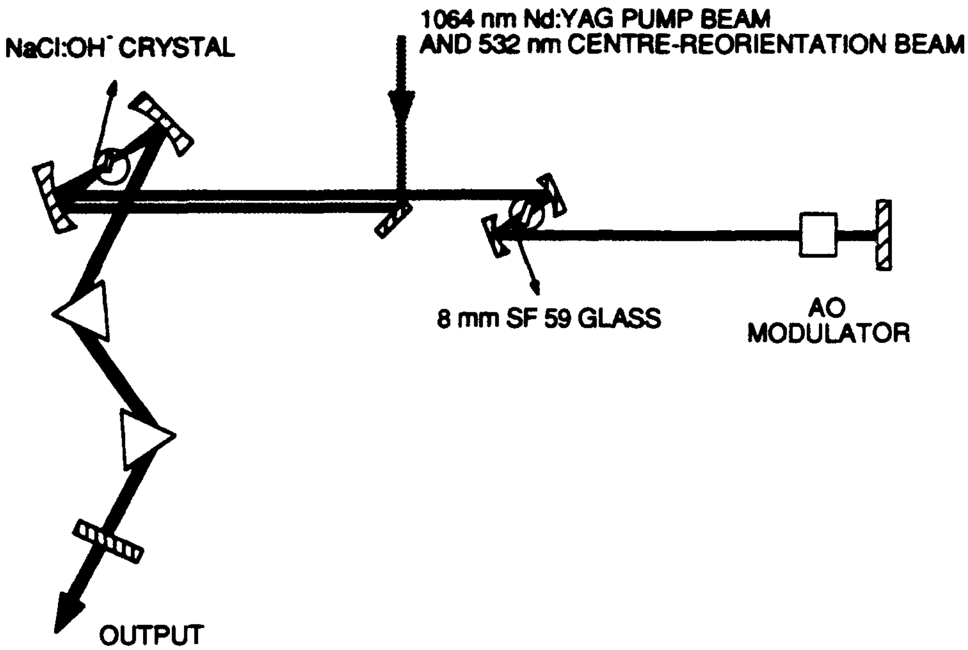

Figure 1. Schematic of the self-mode-locked NaCl:OH⁻ laser cavity

SELF-MODE-LOCKING OF A NaCl:OH⁻ COLOUR-CENTRE LASER

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Self-mode-locking is an attractive means of generating ultrashort pulses from a single-cavity laser[1-3]. The effects of self-focusing and self-phase modulation combined with anomalous group-velocity dispersion are of key importance. In particular, self-focusing of the intracavity beam can lead to changes in the resonator stability characteristics or to a change in the accessible gain volume which play a major role in the self-mode-locking process. We report the first demonstration of the self-mode-locking of a laser in the 1.5 μm spectral region.

A schematic of the self-mode-locked laser configuration is shown in figure 1. The NaCl:OH⁻ crystal was pumped by a mode-locked Nd:YAG laser. A portion of the output from the pump laser was frequency doubled to provide 532 nm light for reorientation of the active centres. The NaCl:OH⁻ colour-centre crystal (cooled to 77 K) was located between two 10 cm radius of curvature mirrors in a, non-collinearly pumped, asymmetric X-fold cavity geometry. Because of its short length and weak nonlinear refractive index there was insufficient self-focusing in the colour-centre crystal alone to cause self-mode-locking so an 8 mm piece of Schott SF 59 glass was placed in an additional focusing section within the longer arm of the cavity. SF 59 glass has a high lead oxide content which results in a nonlinear index of refraction several times that of fused silica. The group-velocity dispersion of the glass was calculated to be +825 fs^2 and so two fused silica prisms were incorporated within the shorter arm of the cavity to ensure overall anomalous group-velocity dispersion. A Brewster-angled, acousto-optic modulator was included at one end of laser cavity and mode-locking was started by the method of regenerative initiation[3].

Careful adjustment of the separation of the focusing mirrors around the SF 59 glass, the location of the glass within the focusing section and the output coupler resulted in self-mode-locking. For a prism separation of 10.5 cm mode-locked pulses of 95 fs duration, having a bandwidth of 27 nm were produced around 1575 nm. The duration-bandwidth product for these pulses was 0.31.

Given the simplicity of the laser cavity we believe that, with further development, the self-mode-locked NaCl:OH⁻ laser may be an attractive source of ultrashort laser pulses around 1.55 μm.

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NONCRITCALLY PHASE-MATCHED, Ti:SAPPHIRE-PUMPED FEMTOSECOND OPTICAL PARAMETRIC OSCILLATOR

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We demonstrate a singly resonant CW femtosecond optical parametric oscillator (OPO) that is externally pumped by a self-mode-locked Ti:sapphire laser and tunable in the near infrared. Previous reports of femtosecond OPO's have been based on a critical, noncollinear phase-matching geometry in KTP.[1-3] We have chosen to use a noncritical phase-matching configuration that avoids the effects of spatial walkoff, and permits collinear propagation of the pump and signal. The femtosecond OPO can deliver average output powers of up to 100 mW in the signal beam alone and is tunable over 1100-1300 nm (signal) and 2300-3400 nm (idler), with appropriate mirrors.

The pump source for the femtosecond OPO is a regeneratively-initiated, dispersion-compensated, self-mode-locked Ti:sapphire laser.[4] The laser routinely delivers 1W of mode-locked power at 830 nm in transform-limited pulses of typically 100 fs duration, at a repetition rate of 84.5 MHz. The OPO is configured in a standing-wave, three-mirror cavity, with the KTP crystal placed at the focus of the resonator. Two of the mirrors are concave with 10 cm radius of curvature and the third is a plane output coupler. The OPO is collinearly pumped, with the pump making a single pass through the cavity. The Ti:sapphire beam is focused into the crystal through one of the concave mirrors, using a 5-cm focal length lens. To avoid feedback, an isolator is used between the pump and the OPO cavity. The KTP crystal is hydrothermally grown and 1.5 mm thick, with a single layer MgF_2 AR-coating centred at 1180 nm on both faces. The crystal is cut for noncritical type II interaction ($e \rightarrow eo$) along the x-axis, with the pump and the resonated signal polarised along the y-axis. The OPO is tuned by rotation of the KTP crystal in the xy-plane or by changing the pump wavelength. The mirrors have >99.7% reflectivity over 1100-1300 nm and >95% transmission at the pump. The output coupler is 1.5% transmitting at the signal wavelength.

The average pump power threshold for the femtosecond OPO is typically 450 mW at the input to the crystal. With 700 mW of pump, the OPO produces as much as 100 mW in the signal beam alone, through the output coupler. This represents a signal extraction efficiency of 14%. Because of the constraints imposed by the collimating and collecting optics, we have not yet been able to measure the total single-pass idler power extracted from the OPO cavity. However, from the ratio of the photon energies we expect that an additional 50-100 mW is generated in the idler beam. The signal output spectra and autocorrelations are clearly indicative of chirped pulses, caused primarily by the self-phase-modulation within the KTP crystal. Without dispersion compensation, the signal pulses are typically 400 fs in duration. By using a two-prism sequence in a double-pass configuration external to the OPO cavity, pulses of 90 fs duration have been obtained. We expect that intracavity dispersion compensation using the prism pair will allow the generation of signal pulses as short as 50 fs and this is currently being implemented. In addition, cavity length stabilisation of the OPO, mode-matching refinements, and new resonator and pumping configurations will lead to further improvements in the OPO performance and these experimental characterisations will be discussed in some detail.

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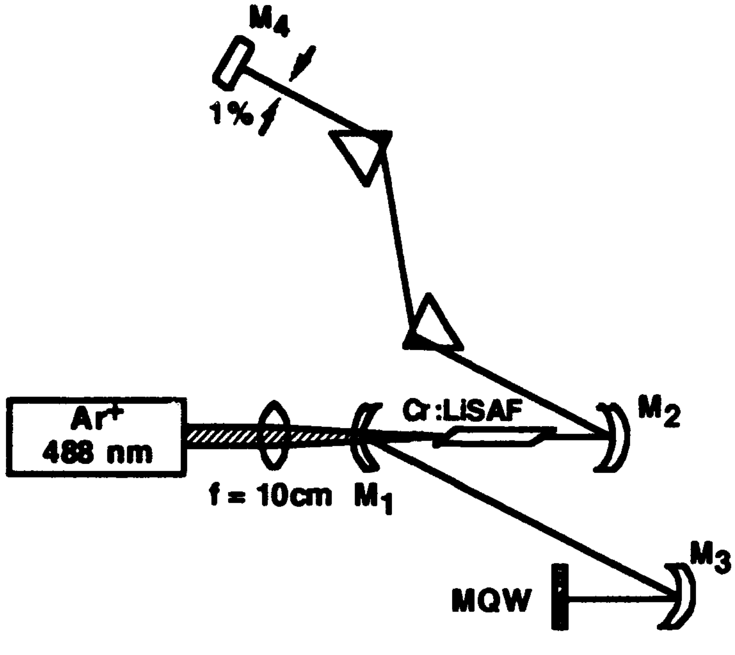

Figure 1 Femtosecond $Cr:LiSrAlF_6$ laser with intracavity MQW absorber

SUB-100 FS SELF-STARTING FEMTOSECOND SOLID-STATE Ci:LiSrAlF$_6$ LASERS

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Tunable solid-state lasers, notably the Ti:sapphire laser, can generate femtosecond pulses as short as ~10 fs by exploiting the optical Kerr effect. Cr^{3+}:LiSrAlF$_6$ is an attractive alternative to Ti:sapphire that may be efficiently pumped by laser diodes at 670 nm and by flash-lamps or arc-lamps.

Our initial experiments concerned a c.w. Cr:LiSrAlF6 laser pumped at 488 nm which was passively mode-locked using a dye jet stream of neocyanine. The relatively dilute saturable absorber in the laser cavity provided a weak modulation, sufficient to initiate the pulse formation. Self-focussing (i.e. KLM) and "soliton shaping" then acted to compress the pulses to sub-50 fs - requiring absorbed pump powers of only 500mW (within the reach of diode lasers). The laser was self-starting and exhibited excellent stability. After optimising the intracavity dispersion using F2 glass prisms, transform-limited pulses as short as 33 fs duration, assuming a sech^2 pulse profile, were obtained.

The low pump powers necessary to achieve femtosecond pulse generation demonstrate that a diode-pumped femtosecond Cr:LiSrAlF$_6$ laser is feasible. In any practical system, however, the saturable absorber dye is clearly undesirable. We therefore have investigated the use of a GaAs/AlGaAs MQW saturable absorber, previously used with a semiconductor laser [1], to initiate the mode-locking. With the MQW absorber in an external cavity at the focus of a x20 microscope objective, pulses as short as 500 fs were observed. This result was achieved by "resonant passive mode-locking" [4] with apparently no significant KLM in the laser cavity. To increase the saturation of the MQW absorber, and to eliminate the cavity matching requirement, the MQW absorber was then located at the focus of an intracavity curved mirror. With this configuration, shown in figure 1, transform-limited pulses of ~90 fs were generated. The cavity was optimised for KLM which produced the expected pulse compression once the intracavity intensity reached the necessary level. The ultimate pulse duration achievable from this scheme is probably limited by the frequency response of the MQW absorber. The laser was self-starting and operated at 850 nm with ~ 10 mW average output power for 480 mW absorbed pump power. Under certain conditions, the laser can be made to operate at two wavelengths simultaneously and produce a THz modulation.

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Z. Su, R. S. Grant, G. T. Kennedy, W. Sibbett and J. S. Aitchison

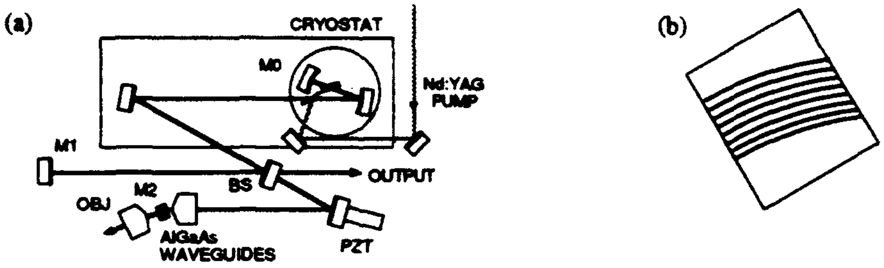

Fig. 1 Schematic of (a) the nonlinear Michelson coupled-cavity mode-locked laser, and (b) the AlGaAs waveguides.

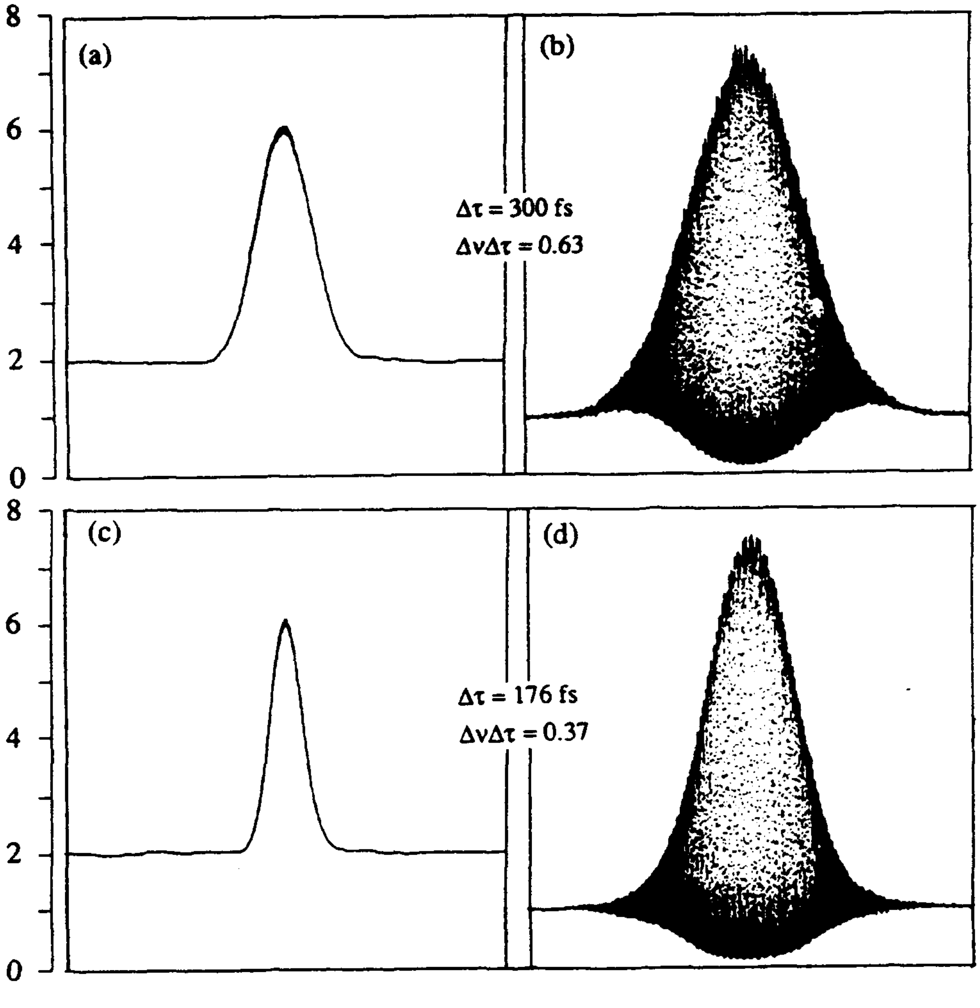

Fig. 2 Intensity and interferometric autocorrelation traces of the output pulses;
(a),(b) without any dispersion compensation inside the cavity,
(c),(d) with a piece of silica glass inside the linear branch of the Michelson cavity.

COUPLED-CAVITY MODE LOCKING USING PASSIVE AlGaAs WAVEGUIDES

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Passive AlGaAs waveguides have been shown to be suitable for all-optical switching at wavelengths corresponding to the half-bandgap.[1] At this wavelength, nonlinear phase shifts in excess of 2π radians can be achieved due to low nonlinear absorption coupled with a localised enhancement in the nonresonant nonlinearity. We have exploited this nonlinearity in our coupled-cavity KCl:Tl colour-centre laser to generate pulse durations shorter than 180 fs.

In the experiments described here the laser was configured in the nonlinear Michelson cavity arrangement,[2] see Fig. 1(a), where the linear branch is represented by the path BS-M1 and the nonlinear branch, incorporating the passive AlGaAs waveguide, by BS-M2. In order to reduce parasitic reflections from the facets of the semiconductor waveguides, the guiding ribs were aligned to meet the input facet at 10° relative to the normal. By curving the ribs such that they met the second facet at normal incidence, this facet formed the end mirror (M2) of the nonlinear branch. The waveguide design, depicted in Fig. 1(b), incorporated 10 guiding ribs of varying widths, each having a path length of 3.5 mm.

In preliminary experiments, pulses as short as 240 fs could be obtained, but these broadened to around 300 fs (Fig. 2(a)) as the pump power was increased to 2 W. Frequency chirp was also apparent in the accompanying interferometric autocorrelations, see Fig. 2(b). The pulse duration was reduced and the frequency chirp eliminated after the addition of elements having anomalous group-velocity dispersion into the laser cavity.[3-5] Pulse durations of around 180 fs were achieved after the introduction of two fused silica glass rods (30 cm total path length) into the nonlinear branch, but similiar results were obtained by adding a fused silica window of 2 mm thickness (at Brewster's angle) into the linear branch, see Figs. 2(c) & (d). Under these conditions, the useful average output power of the laser was in the range 30-40 mW. The effective reflectivity of the waveguide, measured before the microscope objective, was around 3%.

By increasing this reflectivity, and by using shorter guides, we expect that the laser will produce pulses having durations substantially less than 150 fs. We will present details of the performance of the laser with various waveguide configurations, and discuss techniques for group-velocity-dispersion compensation.

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ADVANCES IN II-VI BLUE DIODE LASERS

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The recent control of n- and p-type doping in ZnSe and related II-VI alloys has resulted in the production of the first blue diode lasers over the last two years. Initially produced by the 3M Company [1] and Purdue and Brown Universities [2], over half a dozen research labs around the world, including our own [3], have now demonstrated their own laser structures.

This paper will cover the important breakthroughs which produced these lasers and describe the current designs which are presently being investigated. All the original laser structures were fabricated with ZnSe or ZnSSe cladding and confinement layers with active layers containing ZnCdSe quantum wells, but recently a new quaternary system ZnMgSSe has been investigated. Although this material still has certain drawbacks at present, it has proved to be an excellent material for confinement layers and barriers for ZnCdSe quantum wells [4]. Recent laser structures produced using this material have operated at temperatures up to 394K in pulsed mode [5].

This paper will also highlight a number of areas which are of current interest in the development of blue laser diodes. These include the lasing mechanism, which is currently a matter of some debate. Also, there are a number of problems relating to both the long term stability and degradation of devices and contacting to p-type layers. Recently there have been important advances to at least the problem of producing ohmic contacts on p-type ZnSe [6]

Finally, there have been a number of initial reports relating to the production of optically pumped semiconductor lasers operating at shorter wavelengths [7]. The prospects for these laser systems will be considered.

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VISIBLE FLUORIDE FIBRE LASERS

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Lanthanide-doped fluoride glass fibres have been shown to exhibit a number of visible laser transitions, some of which can be pumped efficiently at infrared wavelengths using excited state absorption processes. These systems look increasingly promising as diode-pumped visible sources with the merit of great simplicity; no phasematching condition need be fulfilled and no stabilization of a diode output or an enhancement cavity is required.

This talk will review recent advances in the field including diode-pumped lasing at 635nm and 520nm in praseodymium-doped fibre and 1.12μm-pumped lasing at 480nm in thulium-doped fibre. Of the optical pumping schemes demonstrated to date several have required simultaneous pumping at two wavelengths, introducing an undesirable degree of complexity. A system which circumvents this problem in the case of the dual wavelength pumped praseodymium upconversion laser will be described.

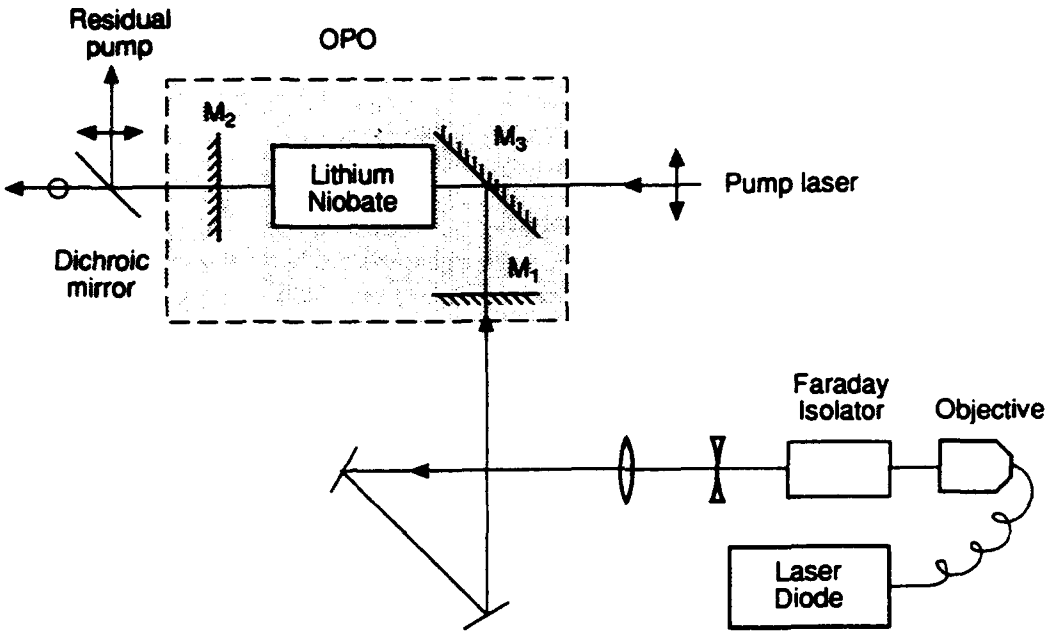

Figure 1 Injection-seeded optical parametric oscillator.

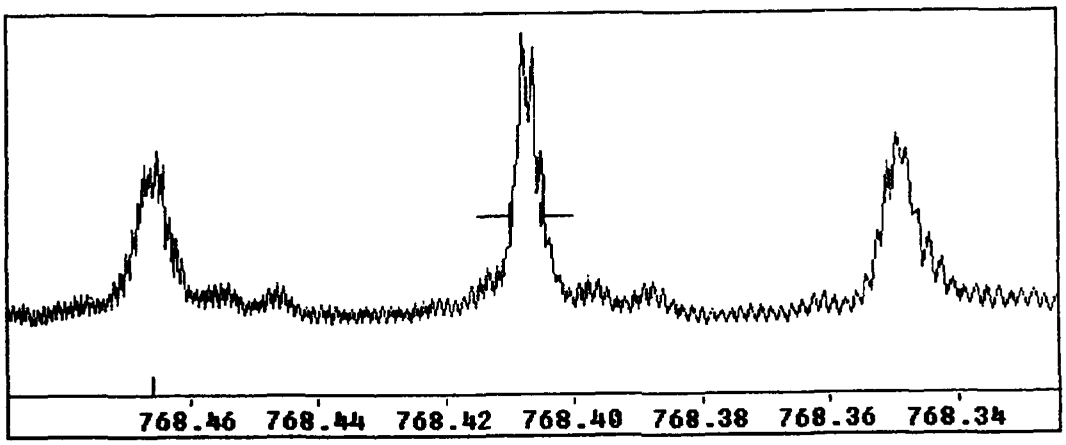

Figure 2 Wavemeter measurement of second harmonic of injection-seeded output from OPO. The etalon fringe at 768.46 has a linewidth of 5.0 pm (equal to the resolution of the etalon).

INJECTION SEEDING OF AN INFRARED OPTICAL PARAMETRIC OSCILLATOR WITH A TUNABLE DIODE LASER

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The optical parametric oscillator (OPO) has been shown to be a versatile source of tunable visible and infrared radiation. However, the wide bandwidth of the output from simple OPO designs precludes their use for many applications. One method used to reduce the bandwidth is injection seeding. In this paper we report successful seeding of a pulsed singly-resonant lithium niobate OPO using a CW diode laser, producing a signal output at 1.54 μm and an idler at 3.45 μm.

A schematic diagram of the experimental set-up is shown in Figure 1. The pump is an injection-seeded Nd-YAG laser, producing 10 nsec pulses at a repetition rate of 10 Hz. After attenuation and collimation the pump beam has a diameter of 4 mm and a maximum energy of 110 mJ per pulse. The seed laser is a distributed feedback diode laser (BT&D) with a nominal output power of 1 mW and a tuning range of 1.535 to 1.538 μm. The seed beam is expanded to a spot size of 2 mm. The OPO cavity is 80 mm long and uses three mirrors. M1 has a reflectivity of 90% at 1.54 μm. This mirror is mounted on a piezoelectric stack which is used to match the length of the cavity to the wavelength of the seed radiation. M2 and M3 have reflectivities of 74% at 1.54 μm. The lithium niobate crystal has dimensions 10x10x50 mm and is anti-reflection coated for wavelengths between 1.5 and 1.6 μm. The signal radiation at 1.5 μm is frequency doubled in another lithium niobate crystal to enable detection by a pulsed wavemeter, which allows the wavelength and bandwidth of the output to be measured.

With the diode laser wavelength set at 1.538 μm, 2.5 mJ of seeded radiation has been measured. This output was stable for several minutes with no cavity adjustment necessary, and could be tuned over 0.6 nm simply by changing the diode temperature and the piezoelectric stack length. The output energy did not change significantly between seeded and unseeded operation, however the output beam diameter decreased considerably. The output bandwidth fell from 100 GHz to less than the resolution limit of the wavemeter (3 GHz), as shown in Figure 2.

This experiment has demonstrated that an OPO together with a widely tunable injection source (such as a grating-tuned diode laser) can be used to generate narrow bandwidth signal wavelengths from 1.5 μm to 1.6 μm, and hence idler radiation from 3.1 to 3.6 μm. This will provide pulsed, narrow bandwidth radiation in a wavelength region useful for atmospheric spectroscopy and other appilcations.

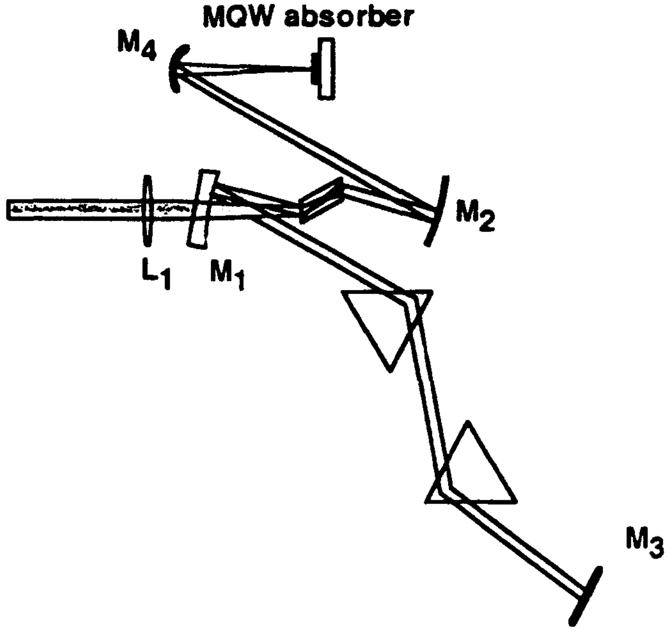

Fig. 1 Schematic of laser cavity

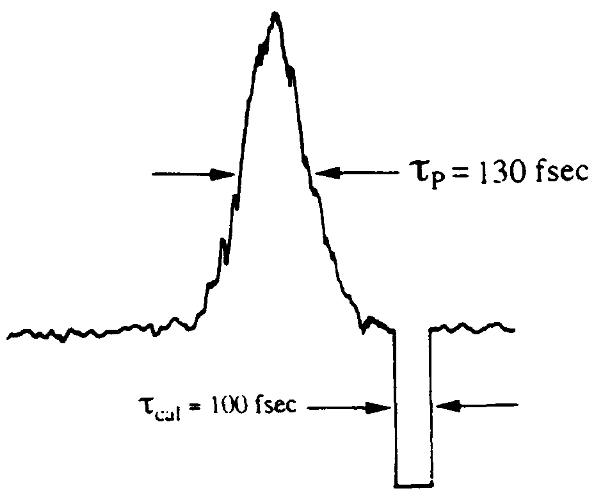

Fig. 2 Autocorrelation trace of shortest pulses obtained.

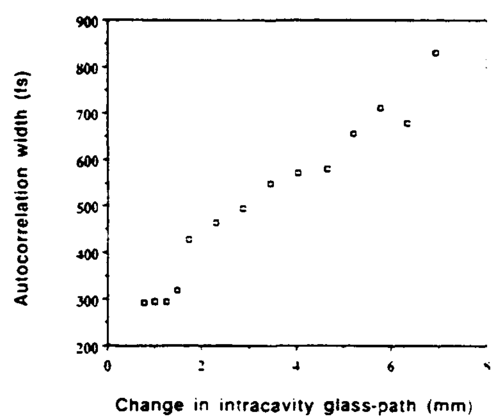

Fig. 3 Variation of autocorrelation FWHM with intracavity glass-path

A SELF-STARTING FEMTOSECOND TI:SAPPHIRE LASER WITH AN INTRACAVITY MULTIPLE QUANTUM WELL ABSORBER

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Titanium-doped sapphire ($Ti:Al_2O_3$) lasers can routinely generate femtosecond pulses and recently, pulse durations below 20 fs have been achieved. The process of Kerr Lens Mode-locking (KLM), which is utilised in these systems, is generally not self-starting and so some additional amplitude modulation is required to initiate the pulse formation. A solid-state saturable absorber is simple, convenient and potentially cheap.

In the work reported here we employ a MQW absorber originally developed for mode-locking external cavity semiconductor diode lasers. The MQW absorber had a carrier lifetime of ~150 ps and an excitonic absorption peak was at 822 nm at room temperature. The small signal reflectivity of the MQW absorber structure was measured to be ~12% at the exciton peak. Figure 1 shows the laser cavity used in this experiment. At above 6 W pump power, stable, self-starting, cw mode-locking was observed. An average output power of 10 mW was measured at 7 W pump power. After optimising the intracavity glass-path, pulses as short as 200 fs duration (assuming a sech^2 pulse profile) were routinely achieved and these were within 10% of their transform-limit. The shortest pulses obtained were of 130 fs duration and an autocorrelation profile of these pulses is shown in Figure 2. The pulse duration was not critically sensitive to the laser alignment and we did not need to employ any intracavity slit or aperture. The use of the intracavity MQW absorber to mode-lock the laser resulted in a shift of the laser spectrum to ~850 nm from its free-running wavelength of ~780 nm.

The use of the MQW absorber intracavity in the laser configuration reported here did not appear to initiate Kerr Lens Mode-locking. For this system, passive mode-locking with the ultrafast excitonic resonant nonlinearity (i.e. a "fast" saturable absorber) appeared to dominate the steady-state laser dynamics, rather than KLM which would be expected to yield pulses of less than 100 fs duration. Some pulse compression was achieved intracavity by the interaction of nonlinear frequency chirp and GVD. Figure 3 shows a plot of pulse duration against intracavity glass-path which shows that the pulse duration increased slowly with increasing positive GVD and stable mode-locking rapidly terminated with increasing negative GVD. This is in contrast to what is normally seen with femtosecond laser systems dominated by positive frequency chirp arising from the optical Kerr effect and suggests that the net intracavity frequency chirp was negative and therefore probably due to the time-dependent saturation of the absorption of the MQW absorber. This observation highlights the possible disadvantages of employing an intracavity MQW absorber.

FORCED Q-SWITCHING OF MULTI-CONTACT InGaAsP LASERS

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High peak power pulse generation using the technique of forced Q-switching of multi-contact MQW InGaAsP semiconductor lasers operating at 1.5μm will be presented. The multiple contact geometry is used to define separate regions of gain or absorption along the axis of the laser cavity. The gain region is forward biased and strongly pumped, whereas the absorber section is reverse biased such that laser oscillation is frustrated. Q-switching is then induced by applying a high frequency signal to the absorber section (in this work a modulation frequency of 1.25GHz was used). In this manner clean, subpulse-free, ultrashort pulses with durations as short as 25ps and peak powers as high as 100mW can be produced. This technique therefore represents an order of magnitude improvement in the peak pulse power of similar gain-switched semiconductor lasers, and also a similar improvement in the pulse energy over that obtained from modelocked systems. Timing jitter measurements also indicate that the pulse train is very stable with values of 65fs (in the region 50-500Hz) and 35fs (500Hz-5kHz) being obtained. Data relating to both Fabry-Perot and DFB laser devices utilising two or three contact geometries will be described.

A LASER DIODE PUMPED OPTICAL AMPLIFIER IN THE FIRST TELECOMMUNICATIONS WINDOW

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Thulium doped fluorozirconate fibre has been shown to operate as an efficient amplifier over the wavelength range 800nm to 815nm in the first telecommunications window. Using a Ti:Sapphire laser at 780nm as pump source we have shown 23dB of gain at 805nm with 60mW of launched pump power[1].

In this paper we will present results of the laser diode pumped operation of a thulium doped fibre laser and also amplifier around 0.8μm. To date we have shown at least 14dB of single pass gain by the diode pumped operation of the resonantly pumped laser at 805nm lasing off of the two bare ends with 4% Fresnel reflections. This was achievable with 39mW of pump light lauched into the single mode fibre from the 100mW single stripe diode laser. The optimum launch design, which allowed a launch efficiency of 57%, will be discussed. Full specifications for this diode pumped fibre laser, along with Q-switched operation will be reported.

We will also be reporting on a system demonstration for the diode pumped optical amplifier in the first telecommunications window. With the benefits of the EDFA at 1.5μm well known, this is of particular interest. The cheap AlGaAs sources and detectors available at this wavelength make the use of this system as an amplifier for local area networks very appealing.

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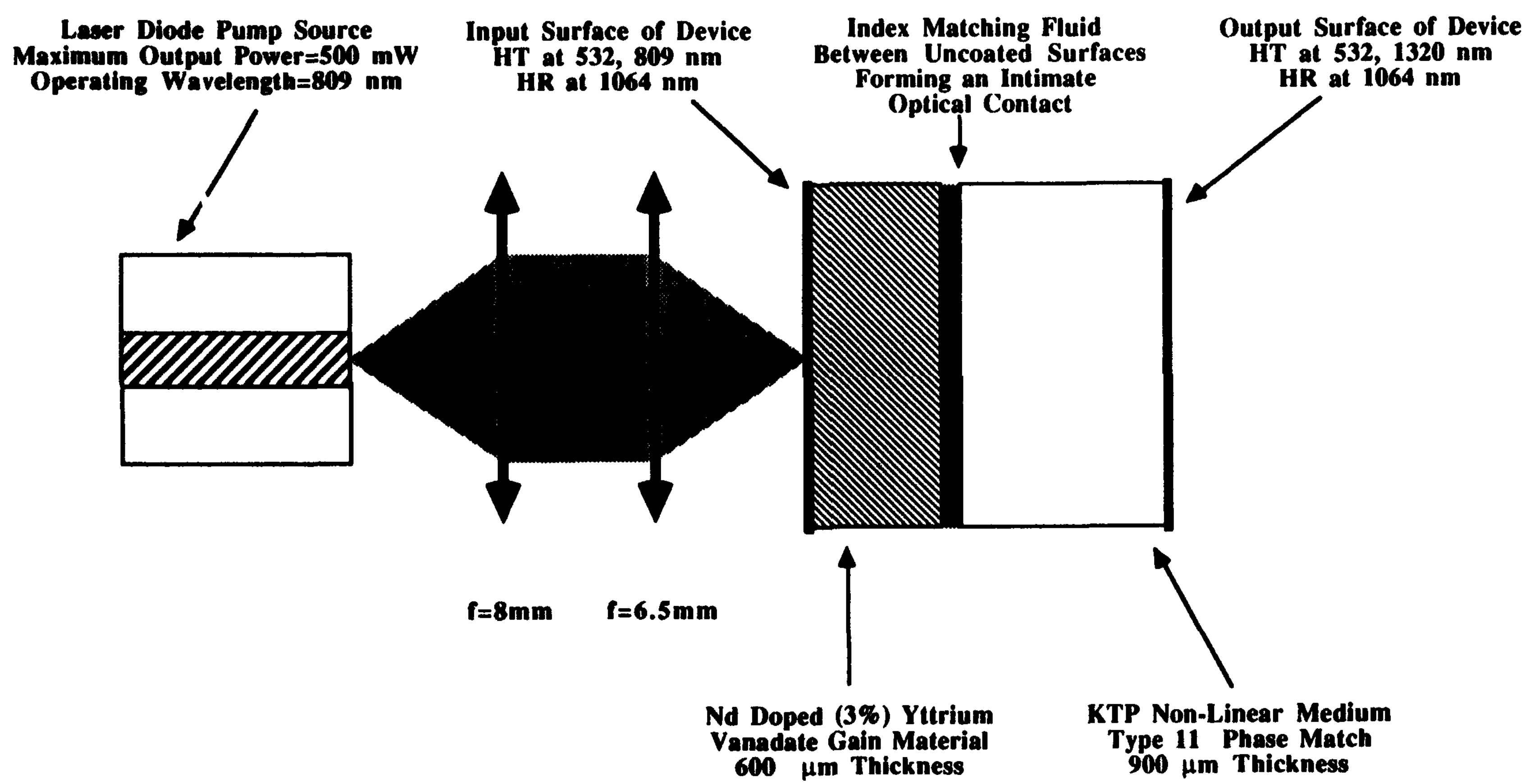

Figure 1: Composite Material Microchip Laser Structure and Pumping Configuration

A LASER DIODE PUMPED, Nd:YVO_4 / KTP, FREQUENCY DOUBLED, COMPOSITE MATERIAL MICROCHIP LASER

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A microchip or cube laser [1,2] is a solid state laser consisting of a gain medium, typically in the sub-millimetre range with nominally plane/parallel surfaces on to which dielectric coatings are deposited directly. To date, work on these ultra compact lasers has centred on low power, continuous wave devices emitting in the spectral region around 1 μm. The microchip concept has however been recently applied to a Q-switched, composite device consisting of a gain section and an electrooptic section [2]. We report here on our contribution to the recent interest in miniature, visible, holosteric lasers [3,4].

We have successfully constructed a composite material microchip laser consisting of a 600 μm thick piece of Nd:YVO_4 as the gain section in intimate optical contact with a nonlinear section consisting of a 900 μm thick piece of KTP angle cut for type II second harmonic generation of 1.047 μm radiation. The device was excited by a laser diode array through coupling optics designed to mimic "butt" [2] coupling of the device directly on to the open facet of the laser diode pump source (see figure 1).The pump power threshold of the device for the fundamental was 14 mW and a slope efficiency of 33 % was achieved. The maximum output power at 1.064 μm was 105 mW for 330 mW of 809 nm pump radiation. The maximum single frequency power at 1.064 μm was 52 mW. The composite material device produced a fundamental output in a near diffraction limited spatial mode at all pump powers.

In addition to the fundamental output a maximum of 0.91 mW of multi-longitudinal mode 532 nm radiation was observed for 330 mW of incident 809 nm pump light. The green output of the device had spatial characteristics identical to those of the fundamental output. The effect of thermally induced waveplating action [3] in the KTP material was examined and found to be minimal even during rapid device switch on from cold to 300 mW of incident pump power. The temporal stability of the intensity of the green emission was examined and no periodic intensity fluctuations due to a sum-frequency process [4] between the two oscillating cavity modes was detected. We attribute the absence of the so-called "green problem" [4] to the very small non-linear coupling coefficient present in the device.

We have also examined a laser diode pumped, composite material device utilising a 250 μm thick piece of lithium neodymium tetraphosphate (LNP) [1] as the gain material and a 900 μm thick piece of KTP as the nonlinear section.. The presence of optimised cavity mirrors and correct KTP angle cut gave 3 mW of 523.5 nm radiation for 250 mW of 801 nm incident pump. We believe that similar adjustments to the characteristics of the Nd:YVO_4 / KTP device will yield significant improvements in the performance of such a composite device thus making the composite material microchip laser concept a viable route to coherent, visible radiation.

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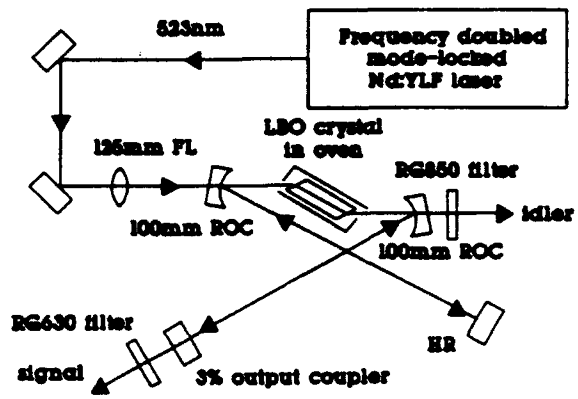

Figure 1. Schematic diagram of the Brewster angled LBO OPO

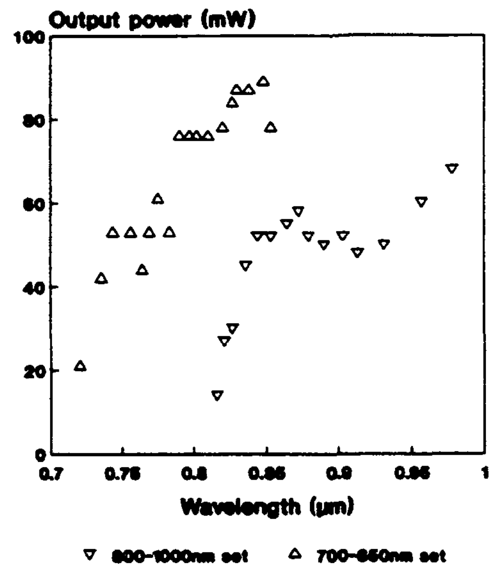

Figure 2. Variation of the resonated wave output power across the tuning range.

AN ALL-SOLID-STATE SYNCHRONOUSLY PUMPED OPTICAL PARAMETRIC OSCILLATOR

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The synchronously pumped optical parametric oscillator (OPO) is potentially the ideal source for the many applications requiring widely tunable ultrashort pulses. For high stability, cw pumped operation is required, with only one of the two generated waves being resonated in a singly resonant oscillator (SRO). For an efficient and compact device, an all-solid-state pump source is favourable. Lithium triborate (LBO) has the attractive property of temperature-tuned exact noncritical phase matching over much of its transparency range. Robertson *et al.* achieved the impressive tuning range of 0.65-2.7μm from an LBO OPO, but little other information for the SRO was reported (1). We recently reported the efficient operation of a similar device, including temporal and spectral data for the SRO (2). However, in that work we only coupled out the nonresonated wave from the OPO. Here, we report the operation of an LBO OPO accessing both of the generated waves as outputs.

The OPO cavity is shown schematically in figure 1. As an improvement on the work reported in (2), we opted to use a Brewster angled crystal. This avoids the restrictions on efficiency and tuning range imposed by spectral roll-off in the antireflection coatings. The 13mm long Brewster crystal was cut for temperature-tuned type I noncritical phase matching propagating along the crystallographic x axis. The LBO crystal was mounted in an oven which could vary the crystal temperature between ambient and $\sim$200°C with a stability of $\pm$0.1°C. The crystal used was of rather poor quality, with a total single pass loss of 0.8% and the crystal having definite sweet spots. The reflection loss from each Brewster surface contributed only 0.1% loss. Using two different mirror sets, the threshold pump power was measured at three different resonated wavelengths to be 170mW average power. The slope efficiency for the resonated wave was 40%, giving rise to an average output power of up to 89mW at 850nm for a pump power of 340mW. The resonated wave could be tuned over the range 978-816nm and 853-721nm, with the nonresonated wave tuning over the range 1126-1460nm and 1355-1911nm. The resonated wave output through the output coupler was >50mW over the range 978-744nm as shown in figure 2, with the nonresonated wave output through the rear curved mirror being >30mW over the range 1164-1813nm. The output pulses from the OPO at 780nm are $\sim$1.5ps duration and exhibit excess bandwidth, with a time-bandwidth product of $\sim$0.9 as in (2). Effective control of the OPO bandwidth should result in transform-limited subpicosecond pulse generation across the entire tuning range.

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FEMTOSECOND STUDIES OF OPTO-ELECTRONIC MATERIALS AND DEVICES

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Abstract

Femtosecond pulses are being used to probe the dynamic nonlinearities of semiconductor diode lasers and amplifiers. With a novel heterodyne detection technique, pump-probe experiments are performed using parallel as well as perpendicular pump and probe polarizations, and index and amplitude dynamics are monitored independently. The effects of two-photon absorption, spectral hole-burning, nonequilibrium carrier distributions and population changes can be delineated for the first time. The information that is being obtained may be used to improve understanding of ultrashort-pulse generation, propagation and distortion in these devices. It may also be related to diode laser modulation nonlinearities and used to provide a basis for designing monolithic modelocked lasers and ultra-highspeed photonic circuits. The fact that large index and gain nonlinearities can be produced without population changes offers the potential for ultrafast all-optical switching in active semiconductor waveguides.

DOPPLER WINDLIDAR FOR SPACE APPLICATIONS

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There is growing interest in the use of use of active remote sensing satellites. One concept is an orbiting Doppler windlidar, arranged to illuminate the Earth's atmosphere and coherently detect radiation backscattered by atmospheric aerosols. The Doppler shift and thus windspeed can be extracted. Using a simple scan pattern, the orbital and planetary spin motion ensure that the whole atmosphere is interrogated every few days with a horizontal length resolution of a few hundred km. Such data should lead to greatly improved weather forecasting and understanding of climate change.

It is widely recognised that the laser transmitter technology is the most critical area in such a development and the current perception worldwide is that carbon dioxide sources are more mature than solid state. DRA has been involved with coherent remote sensing systems and sources for many years, and now is becoming involved with such longer range applications as this. We lead an international team on an advanced research programme of design, construction, and test of a potentially space qualifiable version of such a transmitter source.

The target is emission of 10J output pulses of 5μs duration at 10 Hz prf, with a frequency stability of 200 kHz, with an operating life of several years.

The considerations of system design will be explored in some detail and the latest results of design verification tests on the source lifetime and efficiency will be reported.

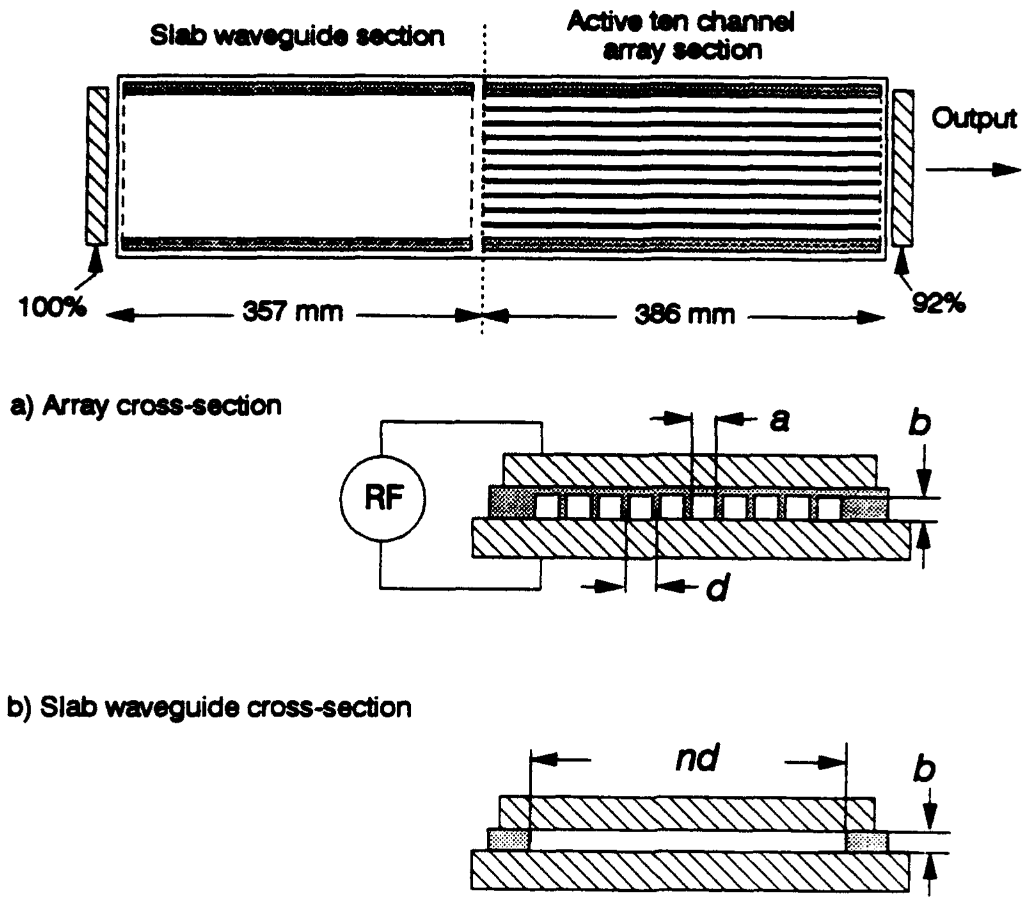

Figure 1. Schematic layout of a ten channel array laser, phase-locked by coupling in a slab waveguide.

CO_2 WAVEGUIDE LASER ARRAYS PHASE-LOCKED BY WAVEGUIDE- CONFINED TALBOT IMAGING.

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RF excitation of arrays of waveguide CO_2 lasers provides devices which are power scalable, with typically 25W per laser channel attainable and up to 750 W in two-dimensional arrays [1]. Previously we have shown that machined ceramic arrays, with channel dimensional accuracies of ~30μm, have a frequency balance of ≤10MHz, suitable for phase-locking techniques to produce scalability of the laser *brightness*. In this paper, diffractive coupling within a section of slab waveguide of Talbot imaging dimensions is investigated as an efficient phase-locking method for planar arrays, as shown in Fig.1. Waveguide confinement within the slab coupling region prevents diffractive loss, greatly increasing the feedback to the array, compared to previously used free-space coupling regions.

Experimentally, phase-locking has been obtained with imaging in the slab section at both the full Talbot distance, $z_T = 2d^2/\lambda$, for 10 and 19 element arrays with a 1.96mm period, and the half Talbot distance, $z_T/2$, for 7 and 13 element arrays with 2.75mm period, respectively. The 7 and 10 element arrays have unlocked frequency spreads of 9 to 15 MHz, consistent with constructional tolerances, and well within the expected locking range for the degree of inter-channel coupling produced by lateral diffraction in the slab section. The 7 and 10 channel devices both produce 100W output powers when phase-locked, i.e 60 to 68% of the multi-frequency output. Guiding loss in the passive slab and non-uniform saturation of the array channels account for much of this power reduction and imaging losses are small.

The 7 element device has also been operated with a discharge in the slab section, with a power output of 40W. This arrangement is similar to the previously reported use of Talbot imaging of a grid for selection of a single mode in a waveguide slab laser [2]. Using two RF power supplies to produce discharges in both the slab and array sections gives a power output of 125W. With active slab section, gas thermal lensing is found to cause an increase in imaging losses, which can be improved by small adjustment of the slab waveguide width.

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THE EFFECTS OF AIR CONTAMINANTS ON XeCl LASER PERFORMANCE

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The effects of traces of air contaminants on the initial laser power and on the gas lifetime of a xenon chloride excimer laser have been studied. Although contaminants such as H_2O and CO_2 have a severe deleterious effect, the dominant species, when present in atmospheric ratios, are O_2 and N_2.

In a well passivated laser with no added impurities the gradual decline in laser output is caused by the internal generation of impurities, and is found to correlate well with the measured amount of CO. Under these circumstances, a halogen injection will <u>reduce</u> the laser output.

Nitrogen impurity has a complex effect with appears to be a combination of optical absorption (presumed caused by long-lived metastables) and chemical reaction, under lasing conditions, with HCl. This forms $NH_4^+Cl^-$ which precipitates out as a white powder, and has been found by FT-IR and FT-Raman spectroscopy to be the dominant particulate species in the laser. Under these conditions, the HCl is depleted through reaction with N_2, and an HCl injection revives the laser output. After sustained operation (3.10[illegible] shots) and repeated halogen injections, the laser performance approaches that of an uncontaminated laser gas mixture. This indicates both that $NH_4^+Cl^-$ is benign to the laser operation, and that, with halogen injections, the gas mixture is self-purifying.

These and similar results for O_2 impurity (which also responds positively to halogen injections) will be described in detail and the implications for laser design, gas specification and laser running costs discussed.

HYSTERESIS EFFECTS IN LASER MODE HOPS

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It is well known that as a single-frequency laser "hops" to a different longitudinal mode, the output power exhibits a discontinuity. This is a clear signature of bistability and hence leads to hysteresis effects when the laser undergoes a tuning cycle. We have studied these effects in an argon-ion laser which has a low finesse intracavity etalon to ensure single-mode operation. Mode hops are produced by temperature scanning this etalon. It is always necessary to tune the etalon resonance frequency well beyond the half-way point between the two relevant modes to induce the mode hop, implying that the lasing mode is reluctant to relinquish its dominant status. Hence, the power is always observed to have increased after the hop.

This discontinuity in power is easily measured, and the experiments show that its value increases with laser power. It can also be severely reduced by "technical" effects such as acoustic vibration. We have developed a theory which explains these hysteresis effects in terms of the gain experienced within the sub-threshold longitudinal modes. The value of this gain is shown to be strongly influenced by a four-wave mixing process which couples the sub-threshold modes on either side of the lasing mode. This mechanism removes energy from the "aspirant" mode, effectively acting as an extra source of loss. Hence, a mode whose cavity losses are smaller than the lasing mode can still be suppressed below threshold.

A comparison of experiment and theory will be presented: the data indicate a tendency for the mode hop to occur slightly earlier than the theory predicts. This is partly accounted for by acoustic and other technical effects. Additionally, the theory makes several simplifying assumptions, whose validity will be considered.

OPTICAL MEASUREMENT OF EXCIMER LASER CURRENT PULSE

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The temporal laser gain profile of a discharge-pumped excimer laser is determined by the shape of the current pulse through the discharge, rather than the applied voltage pulse. Making reliable measurements of the current waveform can be very difficult in the electrically-noisy environment of an excimer laser. An ultrafast optical fibre current sensor has been developed at Salford to measure the shape of the current waveform feeding into the laser discharge.

The sensor is based on the Faraday effect, and measures the rotation of the polarisation plane of light in the magnetic field generated by the current pulse. The sensor is an intrinsic type, where the silica optical fibre itself is used as the sensing medium. It allows non-contact measurements to be made without problems of electrical isolation, impedance matching or radiated electrical noise pick-up. The physical flexibility and small dimensions of the optical fibre allow it to be fitted easily at any point on the power circuit, and readily moved around as required.

Faraday effect fibre optic sensors have been developed by many groups, but generally the low sensitivity of silica to the magnetic fields has forced the use of very long lengths of fibre. The response time of such a sensor is limited by the transit time of light through the fibre, so the bandwidth has to be balanced against the sensitivity. However, in an excimer laser the driving current pulse has a peak magnitude of kiloamps, and so measurable rotations can be generated in even short lengths of fibre.

For the sensor described here, the active part of the sensing fibre is only about 60 cm long, so the response time is 3-4 ns. However, making the sensor robust and stable enough for regular use in an excimer laser power supply has required considerable development work. The performance of the sensor is compared with that of a conventional current-viewing resistor built into the same circuit.

An even faster sensor can be made by using a smaller extrinsic sensing head, made from a solid block of a material with a higher Verdet constant than silica. A sensor of this type, using a crystal of $Bi_{12}GeO_{20}$ as the sensing head, is also described, and its performance compared with the intrinsic fibre sensor.

155 W AVERAGE POWER COPPER HYBRID LASER

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We have developed a copper hybrid laser which produces a maximum average output power (to date) of 155 W at 510.6 and 578.2 nm. The laser has an inner diameter of 63 mm and an active length of 2 m. For output powers of 112 W, the efficiency has reached 3.1%. The laser operates at a pulse recurrence frequency of 18-20 kHz. We will present the latest results of our average-power s aling experiments with copper hybrid lasers.

The laser pulse characteristics of copper hybrid lasers and CVLs will be compared. First, the transverse beam intensity profiles of the copper hybrid laser are Gaussian-like, as opposed to profiles which are uniform or have local on-axis minima as often found in conventional high-power copper vapour lasers (CVLs). Second, in the copper hybrid laser, oscillation begins practically simultaneously (within 3-4 ns) across the bore of the laser. The behaviour is different for CVLs of similar bore, which initially begin lasing near the tube wall, and do not start lasing on the axis of the tube until 15-20 ns later. This is due to poor penetration from the tube wall into the centre of the tube of the longitudinal electric field, *i.e.* due to a 'skin' effect. The difference in behaviour is explicable in terms of the absence of any marked skin effect in the hybrid laser, due to its lower gas conductivity at breakdown. Third, the laser output pulses are considerably longer in hybrid lasers (80-90 ns for the green and yellow pulses separately) compared with ~30 ns for conventional CVLs at maximum output power. The differences in laser pulse characteristics will be discussed in terms of the gas-discharge kinetic processes in the two systems.

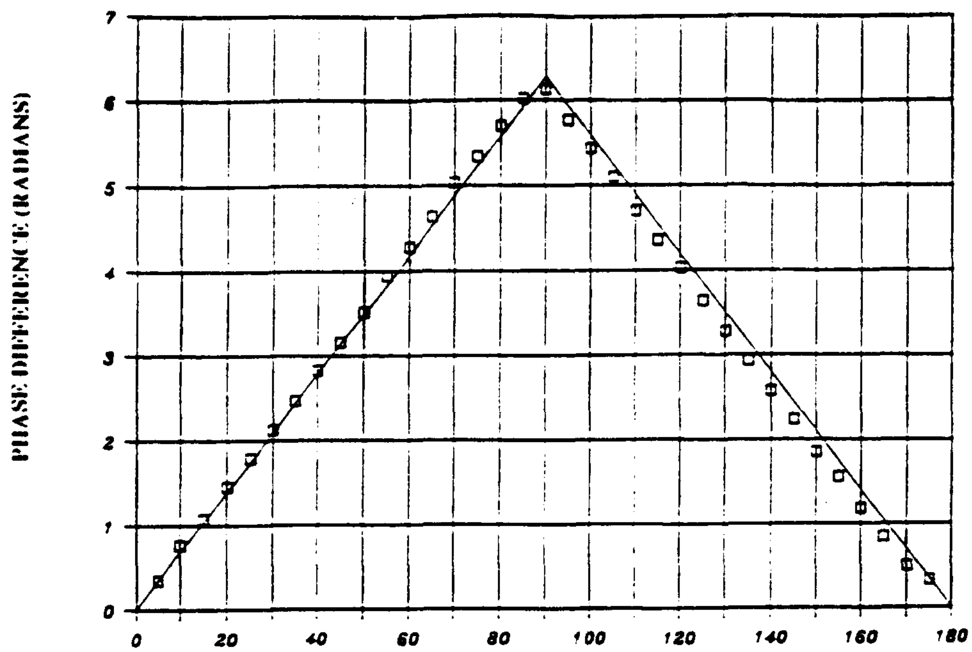
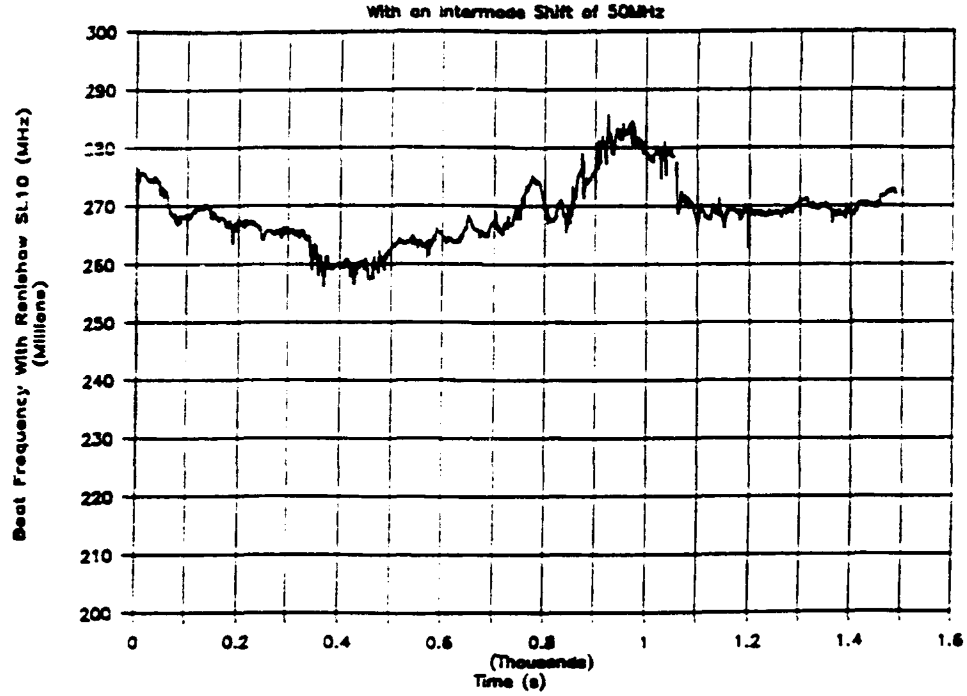


FIG 1 ORIENTATION OF QUARTER WAVE PLATE AXIS (DEGREES)

□ Measured values — Theoretical

FIG 2 Dual Frequency Stabilisation

With an intermode Shift of 50MHz



LONGITUDINAL MODE SEPARATION TUNING IN 633NM HELIUM NEON LASERS USING INDUCED CAVITY BIREFRINGENCE.

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Internal mirror helium neon lasers of about 12cm in length which operate on the 633nm transition will normally oscillate with two modes orthogonally polarized. Small birefringence in the mirrors leads to instability in the polarisation as the modes move in the gain curve due to cavity length changes. Increased cavity birefringence can be realised by intra-cavity insertion of birefringent plates. We present a Jones Matrix analysis of a cavity having two quarter wave plates with their optic axis at an angle θ with respect to each other. It shows that the relative phase between the orthogonally polarised modes can be continuously tuned by variation of the angle, θ. This has the effect of continuously tuning the longitudinal mode separation of the laser cavity.

Normal external mirror helium neon lasers have Brewster angle windows but of course these devices will lase with in only one state of polarisation. To allow the insertion of two quarter wave plates into the cavity and permit both orthogonal polarisation states to lase we have used a tube which is terminated by normal windows with very low loss anti-reflection coatings. The two quarter wave plates are of crystalline quartz and they also have antireflection coatings on all surfaces. Thus the cavity has eight anti-reflection coated surfaces. Without the birefringent plates the output beam of the laser had two orthogonal modes separated by 600MHz. With the quarter wave at one end of the cavity this mode separation could be tuned by relative rotation of the plates. Measurement of the beat frequency between them as a function of the angle between the plates confirmed the predicted linearity as shown in figure 1. In this configuration the modes locked to a single frequency at 41MHz when the axes of the plates were approaching orthogonal and at a lower frequency of 30MHz when their axes were approaching parallel. The locking thresholds were reduced to a value too small to be detected when the tube was placed between the quarter wave plates.

The laser was then actively frequency stabilised using the well established mode balancing technique of Balhorn [1] and the resulting short term stability for the mode spacing set at 50MHz is shown in figure 2. The short term stability of about 20MHz is encouraging since the error signal reduces significantly as the mode spacing reduces.

An envisaged application of this laser is for heterodyne interferometry.

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LINE-TUNABLE MOLECULAR BEAM IODINE LASER FROM 526 nm - 1348 nm*

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The properties and output characteristics are presented of a supersonic molecular beam iodine 3-level laser, optically pumped by an argon ion laser. The supersonic expansion of pure iodine provides for both an enhanced population of the ground state $X\,^1\Sigma^+_{0_g}$, v" = 0, J = 13, 15 of the pump transition (514.5 nm) and much reduced self-absorption in comparison with I_2 cell laser operation. Optical pumping to the v' = 43, J = 12, 16 level of the excited state B $^3\Pi_{0^+_u}$ allows supersonic molecular beam laser operation on the B -> X fluorescent series with terminal laser levels running from v" = 2 to 84 in the X-state.

Visible and near-infrared operation at 57 discrete wavelengths is reported covering the range 526 - 1348 nm in three bands: 526 - 735 nm; 735 - 1000 nm; 1000 - 1348 nm, with 5 - 6 nm steps in the visible, and 10 - 26 nm in the near-infrared. Multiline or single line operation is possible - the latter produced using a birefringent filter placed intracavity. The power output for the v" = 83 terminating transition is 94 mW with 1.1 W input power and 10% output coupler - representing 8.5% optical conversion efficiency. A multiline power output of 160 mW for each of the three spectral ranges is obtained with 1.1 W input power and 7 - 10% output coupler, representing 14.5% power conversion efficiency. As many as 18 lines give a c.w. power output in excess of 10 mW, of which 12 are above 25 mW. The lowest 514.5 nm pump power to achieve threshold oscillation is 5 mW.

At high pump power and high iodine beam flux, transverse laser modes as high as TEM_{80} can be sustained which can be seen in the visible as a ribbon of intracavity light. TEM_{88} modes are also observed. In addition, laser oscillation is achieved on three lines in the visible with 501.7 nm pumping. Upon seeding I_2 in helium carrier gas, laser oscillation is obtained with a nozzle temperature as low as 87°C, in contrast to normal operation with pure iodine of between 130-180°C.

Self-deflection and focusing phenomena are also observed during high power operation of the I_2 laser when the molecular beam is optically pumped with the full argon ion laser power of 1.1 W. The possible origin of these novel features are discussed.

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RELATIONS BETWEEN PREIONIZATION DENSITY DISTRIBUTION, ELECTRODE DESIGN AND EFFICIENCY IN HIGH-PRESSURE DISCHARGE-EXCITED GAS-LASERS

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Certain types of discharge excited gas lasers are routinely operated at pressures of 1 atm or more; these high-pressure glow discharges are formed using preionization, which is effective only when uniform and of adequate density. Using experiments and a two dimensional discharge model, this paper shows that even when these requirements are met, preionization that strays outside the active volume can reduce the laser efficiency by as much as 40 %. The use of wide, smoothly contoured electrodes–such as are used in conjunction with high speed gas flow in high average power lasers–exacerbates this problem. It is therefore important to ensure that preionization is restricted to the active volume of the laser. These results are supported by experiments and the results of self-consistent two dimensional simulations of a compact XeCl laser.

Acknowledgement

The unpublished experiments referred to in this paper were conducted by Dr J. Reid and Dr E. Williams of the Laser Products Division, Lumonics, Inc., Kanata, Ontario, Canada. The author wishes to thank Drs Reid and Williams for their generous assistance.

BEAM QUALITY CHARACTERISTICS OF A FAST-AXIAL-FLOW CARBON MONOXIDE LASER

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The fast-axial flow scheme commonly used for industrial gas lasers has the advantage of a cylindrically symmetric gain region, giving generally good beam quality in low order transverse mode, from simple stable resonators. Discharge non-uniformity and gas turbulence both have a strong impact on the resonator and the consequent beam quality, and may limit the suitability of the laser for specific applications. In this paper, the optical properties of an RF excited, fast axial flow carbon monoxide laser are investigated. The two discharge section laser operates with liquid nitrogen cooling, and gas circulation by a turbo-blower [1], and has recently been improved to give an output power of 500W at 30% power conversion efficiency, with a total discharge length of 0.45m, tube diameter of 17mm and 27MHz excitation frequency.

The gain medium with a *transverse* RF discharge is affected by the uniformity of power deposition, controlled by the profile of the external electrodes, ionization and thermal instabilities related to the operating frequency and input power density, and gas dynamic effects, mainly turbulence and gas temperature variations related to the high mass flow. Unlike DC excited versions, additional turbulence generators in the anode region are not needed to obtain stable discharges, permitting the use of a single stage turbo-blower for gas circulation. A series of measurements aimed at quantifying the effect of each of these aspects on beam quality have been made. Optimisation of the electrode shape has been made, using of a CCD television camera and Beamcode software package to view the axial discharge profile. Highly uniform discharges have been attained up to the threshold power density of ~ 30W/cm^3 for the α to γ discharge instability, which has been observed for the first time under fast-axial flow conditions. Above the discharge instability point, severe discharge non-uniformity is seen, resulting from redistribution of the current density in the near-electrode regions.

The magnitude of angular variations in the resonator axis caused by gas turbulence effects have been measured using a He-Ne probe beam, and position sensitive detector. Random angular fluctuations on the 1 to 100ms time-scale, with amplitudes up to 30μrad. have been detected. The fluctuations are proportional to gas density, and increase rapidly at maximum flow speed. Preliminary analysis of the effect of axis fluctuations of this size for plane / long radius curved mirror cavities shows that there will be little effect on cavities aimed at low order multi-mode operation, but near-single transverse mode designs may have significant power and beam quality fluctuations. Further developments using four discharge sections in a folded cavity are under way.

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BREAKING OF THE TRANSLATIONAL SYMMETRY FOR PATTERN FORMATION IN KERR MEDIA

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Spatial pattern formation in passive media, in presence or in absence of optical cavities, has been recently studied both theoretically and experimentally [1]. Here, we analyse pattern formation in the transverse profile of a laser beam propagating through a thin slice of Kerr medium and reflected back by a mirror after propagation in vacuum [2]. Our approach is based on macroscopic symmetries which can provide a unifying approach to pattern formation in physical systems which differ a lot on microscopic scales.

We use the same model of Ref. [2] but specify boundary conditions corresponding to laser beams with a gaussian intensity profile. Our main result is that transverse boundary conditions modify the symmetry of the solutions with a strong influence on the observed spatial structures.

In the case of plane wave pumps, the system is invariant under translations, reflections and rotations in the transverse plane. In these situations, narrow intense channels of light (filaments) are formed above the instability threshold of the uniform state. These filaments arrange themselves on grids which break the original symmetry but retain a discrete translational symmetry. Typical examples are rolls and lattices of hexagons, only the latter being stable in the Kerr slice [2].

In contrast, boundary conditions that take into account the gaussian intensity profile of real laser beams force the system to be invariant only under rotations and reflections in the transverse plane, the symmetry being reduced to the O_2 group. This allows for the observation of stable solutions in which the filaments form polygonal structures [3]. Such solutions cannot be observed in the plane wave limit case. We also show that the spatio-temporal dynamics is strongly affected by the breaking of the translational symmetry and present evidence of periodic and chaotic alternance. Our results suggest that spatial patterns in many optical experiments performed with gaussian beams should be interpreted in terms of the rotational symmetry only [3].

The presentation is implemented with the use of colour video cassettes for the visualisation of the spatiotemporal dynamics.

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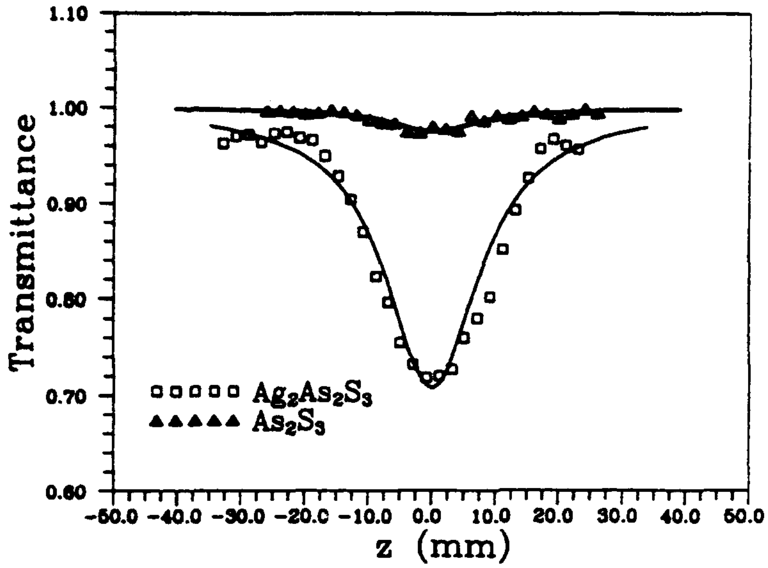

Figure 1: Open aperture z-scan results for both the undoped (triangles) and Ag-doped (squares) As_2S_3 samples. The full lines represent the fits obtained.

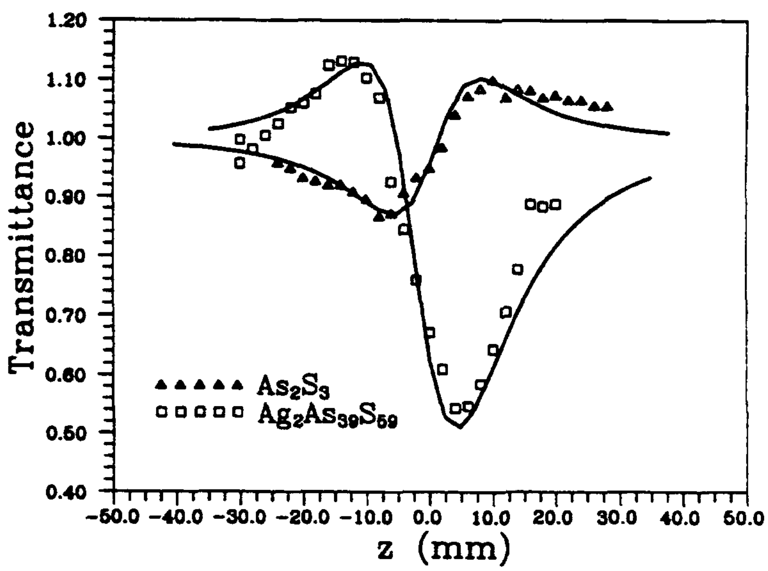

Figure 2: Closed aperture z-scan results for both the undoped (triangles) and Ag-doped (squares) As_2S_3 samples. The full lines represent the fits obtained.

NEAR INFRARED OPTICAL NONLINEARITIES IN AMORPHOUS CHALCOGENIDES

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The nonresonant nonlinearity of transparent glasses has potential for all-optical signal processing applications, provided that a material with a suitably large nonlinearity can be found. Chalcogenide glasses have been shown to have nonlinear refractive index values two orders of magnitude larger than that of pure silica glass [1]. Furthermore, silver doping (photo-doping) of amorphous chalcogenide thin layers is a promising technique for the fabrication of integrated optical devices or waveguiding patterns because of the high resolution and large refractive index difference achievable in addition to the simplicity of this fabrication technique [3]. This work uses the beam distortion technique known as z-scan [3] with picosecond pulses at 1.064 μm to study the off-resonance nonlinear response of undoped and Ag-doped arsenic sulphide. The samples studied were a 1mm thick commercial As_2S_3 infrared window and a 60μm thick $Ag_2As_{39}S_{59}$ polished plate. The calculated optical bandgaps for the samples are 2.365 and 2.30 eV, respectively. The experiments conducted at 1.064μm are close to a two-photon absorption (TPA) resonance ($2\hbar\omega = 2.33eV$). Analysis of the results shows that for the As_2S_3 sample $n_2 = +1.4 \times 10^{-4} cm^2/GW$ and $\beta_2 = 0.26cm/GW$, while for the $Ag_2As_{39}S_{59}$ sample $n_2 = -0.01cm^2/GW$ and $\beta_2 = 99.5cm/GW$. This shows that Ag-doping both enhances the nonlinearity and changes the sign of the refractive nonlinearity. The n_2 value obtained for As_2S_3 falls within a factor of two of the value predicted by the best model for the dispersion in n_2 of crystalline semiconductors near a TPA transition [4]. For $Ag_2As_{39}S_{59}$ the n_2 value does not agree with the theory, since negative values of n_2 should occur only for $\hbar\omega/E_g > 0.69$ while in this case $\hbar\omega/E_g = 0.51$. For materials showing TPA, their use in all-optical applications such as nonlinear directional couplers is possible provided $F = n_2/(2\beta_2\lambda) > 1$ [5]. For the As_2S_3 sample F=2.5 and TPA does not affect its performance, while for the $Ag_2As_{39}S_{59}$ sample F=0.48 which limits its applications.

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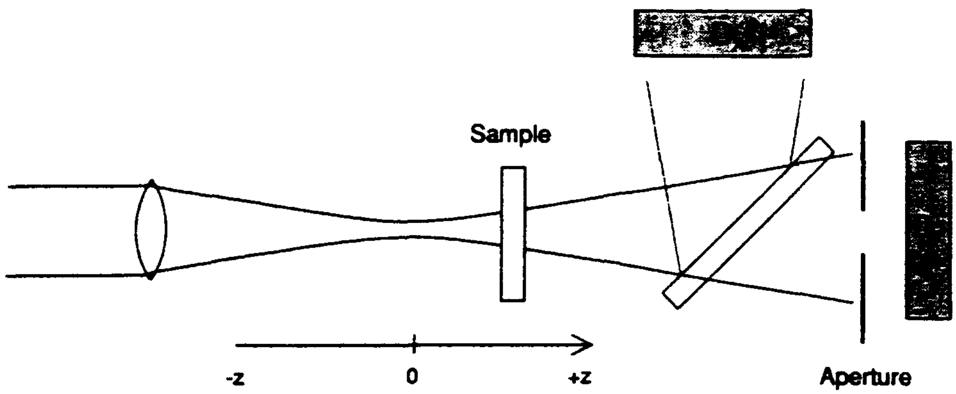

Figure 1: Experimental set-up. Detector D_1 gathers all the light transmitted by the sample and deflected by the beam splitter. Detector D_2 detects the light transmitted through an aperture

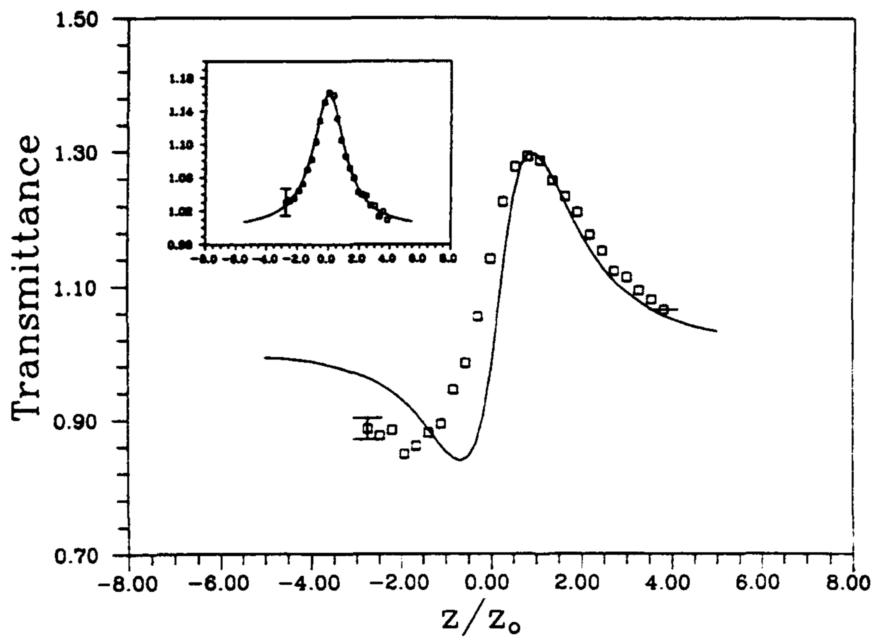

Figure 2: Z-scan results for the $TEA(TCNQ)_2$ in PMMA film. The insert shows the normalized transmittance for the unapertured detector D_1. The main figure shows the normalized transmittance through the apertured detector D_2, where z_0 is the Rayleigh range of the focussed beam. The squares represent the experimental data and the full line the fit obtained.

THIRD ORDER NONLINEARITIES OF $TEA(TCNQ)_2$ DOPED POLYMER FILMS

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The study of the third-order nonlinear properties of organic materials for their potential application in optical information processing devices has been a very active field recently. The required characteristics for such an application are a large nonlinearity, a fast response time and sufficiently low linear and nonlinear absorption. π-conjugated materials fulfill some of these requirements, but their nonlinear absorption usually limits their practical application. One recently proposed alternative [1] is the use of materials with large intermolecular electronic polarizations, such as the charge- transfer (CT) complexes formed by salts of the tetracyanoquinodimethane (TCNQ) donor molecule. The nonlinear response of a polymethylacrylate (PMMA) film doped with the triethylammonium TCNQ salt, $TEA(TCNQ)_2$ is studied with the beam distortion technique known as $z-scan$ [2], using 15 ps duration (HW1/eM) pulses at 532 nm. The film was prepared from a solution of $TEA(TCNQ)_2$ and PMMA in acetonitrile and then deposited onto a glass substrate. The film was heat-treated, above the glass transition temperature of PMMA, to produce crystallites of sub-optical dimensions. The z-scan results show a bleaching nonlinearity that can be characterized by irradiance dependent absorption coefficient $\alpha(I)$ and refractive index $n(I)$ given by $\alpha(I) = \alpha_0/(1 + I/I_s)$ and $n(I) = n_0 + n_2 I$. Analysis of the results shows that for the film in question $I_s = 1.46 GW/cm^2$ and $n_2 = +6.59 \times 10^{-3} cm^2/GW$. Additional DFWM studies with subpicosecond pulses at 712 nm show that the dominant nonlinearity has a response time $\tau = 7ps$. The figure of merit obtained is $F = n_2/(\alpha_0 \tau) = 2.6 \times 10^{-3} cm^3/J$, where we have used $\alpha_0 = 360 cm^{-1}$. This is only about eight times smaller than that of pTS [3] ($F = 2 \times 10^{-2} cm^3/J$), which is one of the best π-conjugated materials known. The sample's fast nonlinearity, together with the absence of an increasing nonlinear absorption and a good figure of merit, make this material a good candidate for application in optical information processing.

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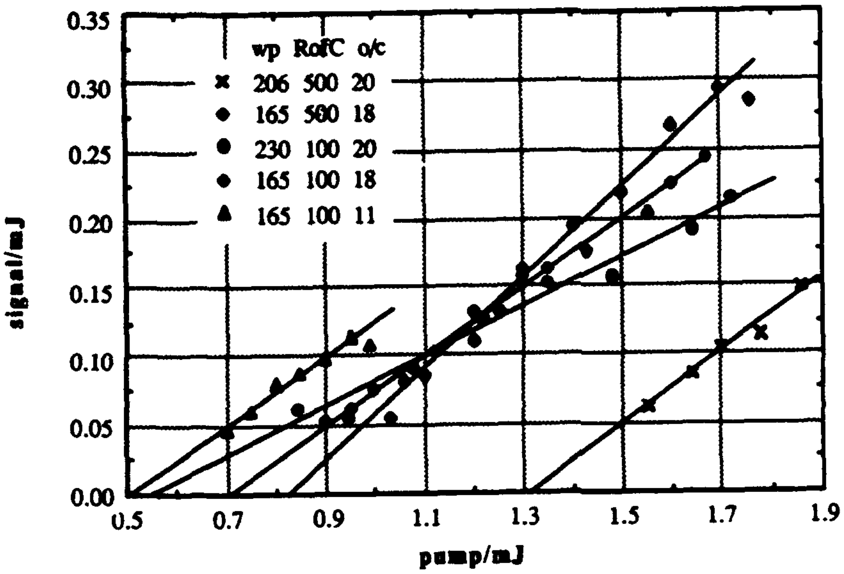

Fig.1 - Summary graph of signal energy v pump energy
where wp = pump spot size. RofC = mirror radii of curvature, in mm
o/c output coupling

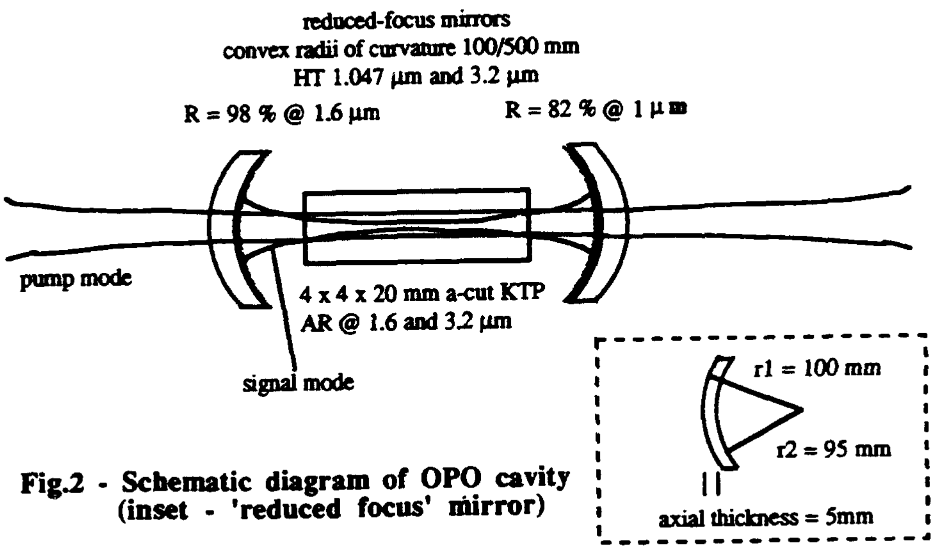

Fig.2 - Schematic diagram of OPO cavity (inset - 'reduced focus' mirror)

LOW THRESHOLD OPERATION OF AN ALL SOLID STATE KTP OPO

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A major factor in the revival in interest of late in the Optical Parametric Oscillator (OPO) has been the continued development of diode-pumped solid-state lasers, and new, and improved, non-linear optical materials [1,2]. We report here on the attainment of 0.5 mJ threshold operation of an all solid state OPO using the material KTP, pumped by a diode pumped, Q-switched Nd:YLF laser. Pump depletion approaching 50 % has been observed, demonstrating that efficient conversion can be obtained with low energy pump sources.

The pump laser used in these experiments is similar to that reported previously [3]. A Nd:YLF rod is end-pumped by a 12 mJ diode laser array, with the pump light collection as in [3]. TEM_{00} mode operation is achieved with the use of an intra-cavity prism pair providing anamorphic expansion. Electro-optic Q-switching of this laser with a $LiNbO_3$ pockells cell produces 1.8 mJ in 18 ns for 12 mJ pump energy.

When the power available from the pump source is limited, it is necessary to consider optimisation of pump and resonated wave focusing to achieve operation of an OPO. In these experiments, the approach to optimum focusing [4] was limited by the resonated beam causing damage to the KTP coatings. The crystal used in these experiments was a 4x4x20 mm a-cut KTP crystal with both faces AR coated at 1.6 and 3.2 μm. This enabled NCPM operation with signal and idler outputs at 1.54 and 3.28 μm respectively. Mode matching to the OPO cavity is achieved with a single 30 cm lens. By investigating pump focusing and different OPO cavities we were able to achieve thresholds ranging from 0.52-1.32 mJ with a, nominally, singly resonant device. A summary of signal energies obtained is shown in fig.1. Pump depletions, indicating conversion to signal and idler, approached 50 %, with external efficiencies into the signal wave as high as 16 %.

We also report on the investigation of spectral properties of the oscillator. Some evidence of double resonance was observed, via the cluster effect [1], but the effect this had on the spectral properties of the oscillator was over-shadowed by the etalon selection of the cavity concave-convex mirrors. The cavity mirrors, which had the inner and outer surfaces concentric for ease of alignment (see fig.2), behaved in a resonant reflector manner, suggesting this as a possible method for achieving single mode operation without the insertion of intra-cavity elements.

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INSTABILITIES IN MODULATED LASERS

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Because of their high stability and relative simplicity, lasers with actively modulated parameters are the most convenient choices for studies on fundamental aspects of nonlinear dynamics in quantum electronics.

In this report we present a review of our recent results on the nonlinear dynamics in modulated lasers [1-3 and references therein]. In the framework of the perturbations theory we have developed analytical methods for estimating of bifurcation boundaries in these lasers. This has allowed to predict some new effects and test them experimentally at the several laser systems. In particular, the theoretical consideration and experimental observation in the cw CO2 laser with an acoustooptical modulator and the ring He-Ne laser gyro with an alternating bias of temporal instabilities and chaos, including such new effects as deterministic phase diffusion, amplification and squeezing near bifurcation points, noncritical slowing down, internal bifurcations of strange attractors, etc., are reported. Experimentally, stable discrete switching of the phase and amplitude of the modulation regimes has been achieved in the generalized multistability domain by means of a short pulsed loss produced by means of an optically controllable intracavity absorption of light in the semiconductor elements of the CO2 laser cavity. These new effects hold great promise for applications, in particular, in intracavity laser measurements and in systems for optical information processing.

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MEASUREMENT OF THE NON-LINEAR REFRACTIVE INDEX OF GASES AT 248 nm

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The limits of performance of high power laser systems are usually set by the non-linear refractive indices of the laser medium and of the medium between the laser and target (usually air). For the KrF laser operating at 248 nm there is the possibility of enhanced n_2 in some gaseous media due to the proximity of VUV resonances.[1] This paper describes the measurement of n_2 in the laser buffer gases Ar, He and Ne, in the atmospheric gases air and N_2 (and by subtraction O_2) and also in CH_4 (frequently used for Raman shifting).

The laser used in these measurements starts with a CW mode-locked Ti-sapphire oscillator operating at 746 nm. The 10 ps output pulses are amplified in a dye amplifier and tripled to 248 nm. Further amplification in a KrF discharge laser gives about 2 mJ per pulse at 8 Hz repetition rate. This near diffraction limited beam was focused with a 2 m lens into a 4 m long gas cell giving an intensity-length product in the region of 20 TW/cm. The maximum usable pressure was 10 bar. The spectrum of the transmitted pulse was recorded using a spectrometer with a resolution of 0.2 cm^{-1}.

As the gas pressure is increased the effect of n_2 is to introduce self-phase modulation on the pulse which is observed as a change in the spectral profile. In CH_4 and air the spectral shape changed with only a few hundred Torr pressure in the cell whereas no change in spectrum was observed in He even at 10 bar pressure. The data are analysed by fitting the observed spectra to spectra simulated from an assumed initial pulse shape with the B-integral as a parameter. The choice of initial pulse shape has been found to be crucial in this process. To date, the best fits have come from a $sech^2$ pulse allowing for the distortions introduced by frequency tripling and amplifier saturation. This analysis is continuing and results will be presented at the meeting.

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NONLINEAR PROPAGATION OF PARTIALLY POLARIZED LIGHT

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For the first time we have developed a general analytical formalism describing the evolution of intense partially polarized light (i.e. mixture of a component with fixed polarization and a randomly polarized component) propagating in a nonlinear medium. The formalism presumes Gaussian statistics for the unpolarized component of light and is based on the matrix presentation of the nonlinear wave equation. It is suitable for description of self action polarization effects in anisotropic, nonlinear, nonlocal dissipative media with arbitrary symmetry of the nonlinear optical susceptibilities and in particular may be used for treatment of optical fibers and crystals of various symmetry.

Exploiting this formalism we found the following properties of partially polarized light propagation:

- **Totally polarized**, coherent light in linear and nonlinear optics remains totally polarized in any circumstances. Consequently light self-action may not lead to its depolarization;
- **Linear optics**. It is known fact that the degree of polarization may change due to predominant absorption of one of the eigenmodes which is the known fact. However we found for the first time that in media of some particular crystal symmetries, time-non- reversible contributions to the optical response (i.e. due to the broken Onsager symmetry) may be the only reason for variation of the polarization degree. This may happen for example in $\bar{4}3m$ crystal class, where time reversible absorption is completely isotropic and no alteration of the polarization degree appears due to it. However time non-reversible nonlocal response may lead to change of the polarization degree. A similar situation, i.e, when the time nonreversible response is the only reason for alteration of the degree of polarization, may be found for light propagating along the optical axis, for example, in crystals of 3, $\bar{3}$, 4, $\bar{4}$, 4/m, 4mm, $\bar{4}2m$ point groups. This may be used for detection of the time-nonreversible state in solids, specifically in excited semiconductors and high-T_c superconductors which have become a field of growing interest.
- **Nonlinear optics**. An intensity-dependent change of the degree of polarization may be expected in a dissipative system with anisotropic nonlinear absorption. However in contradiction to some previously reported theoretical results, a less trivial conclusion may be found, which is that in an absorption-less system, with isotropic nonlinear response, no intensity-dependent change of the degree of polarization may be expected. This model of isotropic nonlinearity is widely accepted in fiber optics. We also specifically note that polarization symmetry breaking i.e. lost of stability of a "fast" polarization eigenmode in a weakly birefringent fiber does not affect the degree of polarization. However the intensity threshold of the symmetry breaking increases with decrease of the polarization degree. We also provide arguments for the more broad hypothesis that in any dissipation-free medium, no change of polarization degree may be expected for any symmetry of linear or nonlinear response.

ABSORPTION AND EMISSION SPECTRA OF TRAPPED TWO-LEVEL IONS IN THE LAMB-DICKE LIMIT

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We present investigations of the resonance fluorescence emission and absorption spectra of a harmonically trapped two level ion. The resonance fluorescence spectrum of two level ions in trapping potentials has been of interest recently especially in view of laser cooling and prospects for ultra-high resolution spectroscopy. We calculate the exact emission and absorption spectra by following the method of Agarwal et al. [1]. This method has been extremely successful in predicting line-narrowing in three-level atoms under the action of two laser beams [2]. These effects were later observed experimentally [3]. The master equation of the density matrix is derived from a semiclassical Hamiltonian. The correlation function for the total atomic polarisation is evaluated by using the Quantum Regression Theorem and the incoherent part of the emission spectrum obtained. The final matrix equations, whilst being too large and complicated to be transparent to analytical investigations, are ideally suited to numerical analysis. Another advantage of our approach is that the absorption spectrum of a weak probe can also be evaluated with relatively little extra work via linear-response theory [4].

The calculations are carried out in the Lamb-Dicke limit of tight localisation of the ion where only the lowest levels of the harmonic trap are involved. Additional sharp peaks are found to appear in the spectra at frequencies detuned from line centre by steps of the trap frequency. These are similar to the results of Lindberg [5]. The generality of our procedure, however, allows the exploration of several experimental conditions not available to previous analyses. New features of the absorption spectra are also discussed.

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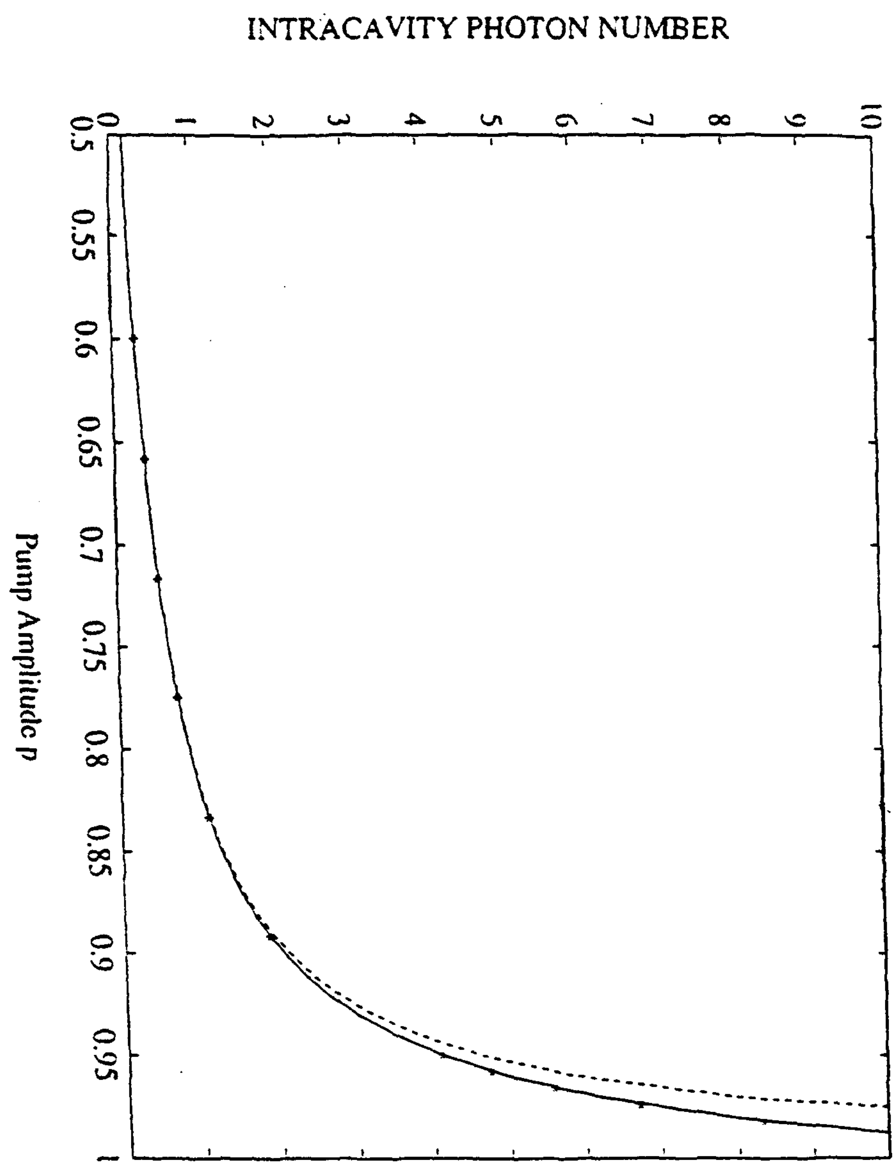
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0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
Pump Amplitude p

GREEN'S FUNCTION THEORY OF THE PARAMETRIC OSCILLATOR

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The quantum statistical properties of E. M. fields produced by nonlinear mixing are now quite well understood in the semiclassical limit. In the case of the optical parametric oscillator, the semiclassical limit is defined by the condition $n_{th} \gg 1$, where n_{th} is the number of intracavity pump photons required to reach oscillation threshold. In this limit, the quantum noise may be treated as a small perturbation to the classical dynamics. As n_{th} decreases, the importance of the quantum noise grows, and new physics is to be expected in the quantum limit $n_{th} \leq 1$. This may be achieved by increasing the medium nonlinearity and cavity Q, and decreasing the cavity mode volume. In this regime the OPO offers the possibility of investigating quantum dissipative behaviour far from equilibrium.

The quantum limit is difficult to deal with because the dynamics has to be treated non-perturbatively. Conventional quantum optical techniques are not generally adequate, although, in special circumstances, such methods as the adiabatic approximation may be applied. Here we employ the non-equilibrium Green's function technique, which proves to be sufficiently powerful to deal quite generally with the nonlinear features, but yet allows for physical interpretation through Feynmann diagrams. Single photon Green's functions are used to compute dynamic spectra of the output using a self-consistent scheme which incorporates nonlinear, many-photon effects. For the first time, dynamic output spectra and quantum noise properties beyond the adiabatic approximation are presented.

The only work with which we can compare ours is the adiabatic theory. In the figure we compare the Green's function results ($\times$) with this adiabatic theory (solid line) in the adiabatic limit, plotting the intracavity photon number versus normalized pump parameter p ($p = 1$ is threshold) with $n_{th} = 10$. The linear theory is shown dotted for comparison.

THREE-LEVEL ATOM IN A SQUEEZED VACUUM

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Since the generation of squeezed light has been successfully demonstrated in several laboratories [1], interest is turning to the distinctive features of the interaction of squeezed light with atomic systems. Two level systems have already received some attention, and interesting properties have been predicted [2].

Here we consider a three level atom in any of its possible configurations, ladder, lambda or vee, which interacts with two classical, resonant, monochromatic electromagnetic fields. We suppose the levels $|0\rangle, |1\rangle$ and $|2\rangle$ to be unequally spaced, so that one field strongly couples only the 0-1 transition, and another field only the 1-2 transition. We further assume that the atom is interacting with two squeezed fields, one centred on each of the two transition frequencies. In addition to the squeezed field, it is important to see how conventional dissipative processes affect the dynamics, and in particular, how they modify the distinctive features due to the non-classical field. The effects of collisions, as an example of a conventional dissipative process, are therefore also included. We develop a unified description of the properties of the three-level system (as far as possible independent of the particular configuration) which is based upon an exact rate equation/diagrammatic approach [3]. We show that the atomic populations are strongly affected by the squeezing phases, the degree of squeezing and the intensities of the applied fields, in addition to the collisions. We also demonstrate that resonance fluorescence in these systems shows distinctive features due to its interaction with the squeezed field.

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NON-DIFFUSIVE PHASE DYNAMICS FROM LINEAR AMPLIFIERS AND ATTENUATORS

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Previous studies of the squeezing properties of phase-sensitive attenuators have shown that light which is initially in a coherent state can become squeezed after passing through such an attenuator. Because squeezed light has non-random phase properties it then follows that linear attenuators can have a non-diffusive effect on the phase of the light. To date, however, studies of the phase properties of linear amplifiers and attenuators have been restricted to the intense field regime where the effect on the phase of single mode light is found to be *diffusive*. The weak field limit, where the contribution of phase-sensitive noise from linear attenuators is most significant, has until now not been studied.

In this paper we give an analytical analysis of linear amplification and attenuation in the weak-field regime that clearly reveals the *non-diffusive* effect on the phase. Indeed we show that a field which initially has a uniform phase probability density can inherit non-random phase properties from *both* phase-sensitive attenuators and amplifiers. In contrast, we find that phase-insensitive amplifiers and attenuators have merely a diffusive effect on the phase of the light. We also present results of a numerical study which show that the non-random phase properties are retained even after large amplifications and attenuations.

TWO-MODE SQUEEZED GAUSSONS

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Two-mode squeezed Gaussons [1] are the natural product of the coherent interaction between squeezed beams. Their general form is intermediate between conventional single-mode and two-mode squeezed states. We describe some of their properties.

Gaussons [2],[3] are states of the electromagnetic field which have Gaussian Wigner functions. This Gaussian profile is retained under the evolution generated by the free Hamiltonian. They are of special interest because they are the only pure states for which the Wigner function is everywhere positive [4]. Gaussons include the familiar coherent and ideal squeezed states. However, more general forms exist for multimode fields. We investigate a class of two-mode Gaussons exhibiting squeezing [1]. These states are two-mode squeezed states but of a more general type than those usually bearing the name [5]. Specifically, the states under consideration are two-mode states intermediate between the conventional single-mode and two-mode squeezed states.

Our two-mode squeezed Gaussons are generated by coherent mixing of two single-mode squeezed states. Their form is similar to a class of generalised squeezed states investigated by Abdalla [6],[7]. A simple method for generating two-mode squeezed Gaussons is to mix two single-mode squeezed states at a beam-splitter. We find that when two single-mode squeezed states are coherently mixed at a 50/50 beam-splitter, the output state and its properties can be varied through a continuous range of behaviour intermediate between single-mode squeezing and two-mode squeezing. This is achieved by varying the difference in squeezing angle of the input squeezed states through a range of π. We illustrate this novel effect by calculating the squeezing properties and the photon number and phase properties of two-mode squeezed Gaussons. A method of generating two-mode squeezed Gaussons whose modes have different frequencies is proposed. This is based on recent work carried out by Kumar [8] on the quantum frequency converter.

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CALCULATIONS AND EXPERIMENTS ON RADIATIVELY COUPLED SURFACE PLASMON POLARITONS IN REAL DEVICE GEOMETRIES

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In all situations of practical interest in which surface plasmon polaritons (SPPs) are used there is coupling to free electromagnetic radiation. This includes light emitting devices, SPP enhanced photodetectors and SPP mediated spatial light modulators, chemical sensors and polarisation filters. However, even in simple planar geometries which facilitate wavevector matching between SPPs and light (ie prism coupling geometries) the basic set of equations describing SPP propagation leads to anomalous results, particularly with regard to damping[1]. Here we examine the implicit dispersion/damping relations for SPPs in multilayered systems, describe how these relate to conventional calculations of reflectance (the optical quantity most frequently measured in SPP experiments) and give a physical interpretation of our calculations in relation to experimental results on prism coupled metal-oxide-metal tunnel junctions. In these light emitting devices understanding of the intrinsic electromagnetic damping of the various SPP modes is important since it competes directly with the desired radiative damping.

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TOLERANCE ANALYSIS OF THE SYMMETRIC SELF-ELECTRO-OPTIC-EFFECT DEVICE WITHIN CASCADED DIGITAL OPTICAL ARRAYS.

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The symmetric self-electro-optic-effect device(S-SEED) has attracted considerable interest over the last few years as a important component in optical computing demonstrators or in photonic switching fabrics. We develop an "idealized" model of the S-SEED optical characteristics to quantify the tolerance of the device on the control parameters. The model encompassses the static and dynamic behaviour of the device while providing analytic solutions for the operating conditions of S-SEED arrays in a cascaded digital optical circuitry. We use the tolerance methodology applied successfully in non linear interference filters optical logic component[Wherrett] in order to assess the robustness of the S-SEED control parameters in the cases of balance and unbalance of the various beams powers. Results are compared with experimental data of the optical characteristics of an GaAs/AlGaAs SEED. The model allows us also to determine the optimum frequency of operation and the optimum control parameters to be used in cascaded digital optical arrays configuration.

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POST-GROWTH IMPROVEMENT OF ASYMMETRIC FABRY-PÉROT MODULATOR CHARACTERISTICS.

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As resonant devices, transverse Asymmetric Fabry-Pérot Modulators (AFPMs) show very good modulation capabilities such as high speed, high contrast and low voltage operation[1]. These devices consist of quantum well layers in an optical cavity and depend on electric-field shifting of an excitonic absorption edge near a Fabry-Pérot (FP) resonance. Critical parameters in the design of such devices are the resonance wavelength, λ_{FP}, and the exciton heavy-hole to FP resonance wavelength separation, $\Delta\lambda$. While high wafer uniformity has been achieved making the production of arrays feasible[2], a number of growth iterations are required to optimise these parameters since they are very sensitive to growth thickness[3].

This paper demonstrates three methods of controlling λ_{FP} and $\Delta\lambda$ using; (i) Impurity-Free Vacancy Disordering (IFVD), (ii) Etching and (iii) Incident Angle Control. The first technique (IFVD) is used to shift the exciton peak to shorter wavelengths, allowing an increase in $\Delta\lambda$ of 6-10nm. The change in modulation characteristics with exciton position is measured. Etching of the top mirror layer is used to alter the mirror amplitude and phase reflectance, modifying the finesse and resonance wavelength (respectively) of the cavity. Increasing the angle of the incident beam reduces λ_{FP} (and $\Delta\lambda$). This allows in-situ optimisation of the contrast or insertion loss of the device by choosing an appropriate angle of incidence. Resonance shifts of approximately 0.3nm/degree have been measured.

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THE FORMATI^N OF OHMIC CONTACTS TO ZnS THIN FILMS

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ZnS is a large bandgap, non-amphoteric semiconductor and the formation of low barrier or ohmic contacts has proven to be very difficult preventing the accurate determination of other fundamental properties such as carrier concentration, mobility and lifetimes. Limited success has been achieved on single crystal ZnS using indium metal with evidence that contact is more probably made by liquid-phase epitaxy rather than diffusion[1]. Such contacts, however, can often revert to the non-ohmic state within a short period of time. Doping by indium diffusion requires a temperature of at least 600°C and is hampered by high levels of defect compensation. For high field electroluminescent device layers the temperature is limited to 500°C and defect compensation can be expected to be large.

For low temperature contact formation the major problem is obtaining sufficient wetting of the indium onto ZnS in order to provide a wide area intimate contact. In an attempt to overcome this, indium was evaporated onto SnO_2 substrates which were then heated in argon (10mTorr) to 180°C-200°C. The indium melting point is 160°C and ZnS:Mn was sputtered onto the molten layer and then annealed to 450°C. The indium was observed to react with the SnO_2 becoming semi-transparent. SEM observation of the ZnS layer shows indium incorporation, in ball form, throughout the layer, a feature also reported in the Au/Te/Au/GaAs system[2]. Contacts have also been formed by melting indium onto sputtered ZnS followed by annealing to 450°C. In-ZnS-In, Al-ZnS-In and Al-ZnS-Al diode IV characteristics show that an ohmic or low barrier contact is formed with indium, the current levels being typically five orders of magnitude greater than with the high barrier Al contact. The threshold voltage for reverse biased light emission was found to be reduced by approximately 30V to 150V compared with the Al contact. This further indicates that conduction is through the ZnS and not via some indium metal path. Indium contacts formed by either method were found to revert to the high barrier non-conducting state after 24 hours unless quenched at the anneal stage whereupon they have remained stable.

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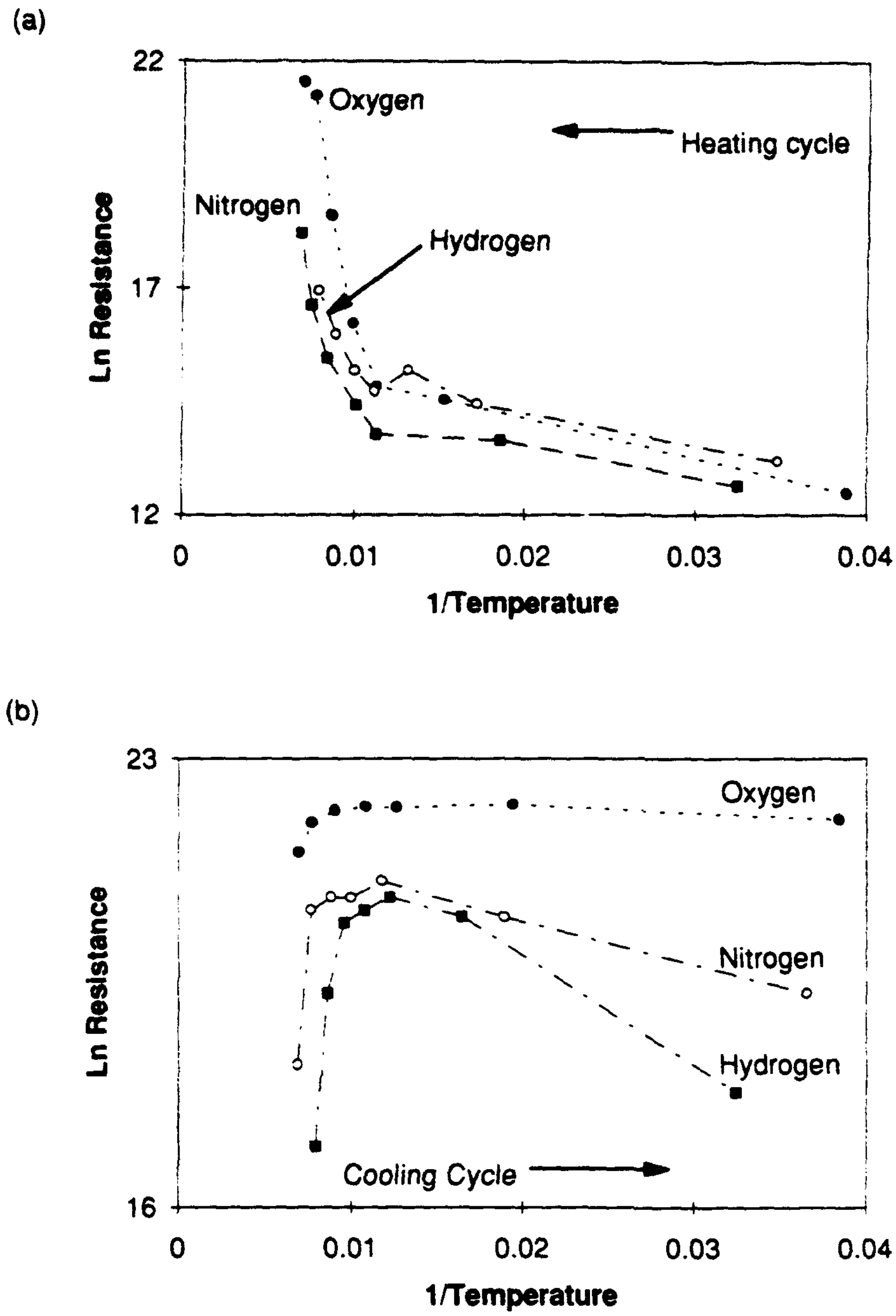

Figure 1. Resistance v inverse temperature plots for various ambients, (a) heating cycle, (b) cooling cycle. Max applied 1V. Uniform temperature.

THE Cu_xS-ZnS SYSTEM IN ELECTROLUMINESCENT DEVICES

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Large area, dc driven, high field electroluminescent devices have been widely researched in the past for their potential low voltage operation but efficiency and stability are still very poor. Although unsuitable therefore as light emitting devices they can be a very useful test vehicle for determining the luminescent properties of zinc sulphide that are otherwise screened by the insulating layers in a standard ac voltage driven (*MISIM*) device. Current dc devices are based on ZnS:Mn powder grains with a 5nm surface layer of Cu_xS and in order to replicate this structure with thin film ZnS a fuller understanding of the nature of the heterojunction is required. The powder nature of the structure has to date imposed a severe limitation on accurate and reproducible experimentation.

The as-formed Cu_xS is thought to have a stable stoichiometry ($1.8 < x < 2.0$) and the overall structure is conductive. XPS/Auger analysis of the surface has shown the layer to be close to Cu_2O, Cu_2S or Cu metal with no trace of CuS. A dielectric region is created at the anode by current heating in order to support the high electric fields required. There have been a number of mechanisms postulated for this but no definitive evidence is available. We have found, by cross-sectional EDS analysis, that mobile copper ions migrate from anode to cathode until the dielectric layer is formed. The loss of copper from the Cu_xS layer, x decreasing, can be expected however to increase the conductivity due to an increase in copper vacancies. Therefore all the Cu must be removed or some of the vacancies are filled by mobile Zn or Mn ions. During the formation process the temperature was found to increase until light emission occurred whilst external cooling caused the process to be retarded. Similar retardation was observed when formation attempted in a semi-inert ambient (the powder binder is an oxidant). Oxidation will increase the Cu_xS layer conductivity by creating Cu vacancies but because of the layer thickness, <5nm, the actual resistance will increase.

In order to investigate each mechanism non-light emitting structures were built, without binder, and with external control and monitoring of temperature within the structure. Cu migration was prevented by maintaining a uniform temperature profile with low applied voltages. It was found that a sharp irreversible rise in resistance occurred at approximately 100°C irrespective of the rate of temperature rise. With thin film Cu_xS resistance increases are due to crystal phase changes but are reversible. In inert ambients the transition temperature is increased whilst with 100% O_2 a very sharp transition is observed. In a reducing ambient the irreversibility is much less marked, figure 1.

POCKELS EFFECT IN ASFP MQW MODULATORS

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Multiple Quantum Well (MQW) electro-absorption modulators within an Asymmetric Fabry-Pérot (ASFP) resonator have been extensively studied[1-3]. Attention has been focused on the performance parameters such as contrast ratio, insertion loss and maximum change in reflection. The later represents the figure of merit of the device as an amplitude modulator.

Many other authors, using this same structure on GaAs/AlGaAs, measured experimentally the change in absorption and using this data, calculated the expected change in the refractive index using Kramers-Kronig[4-5] relation.

In our work, we measured experimentally, both the change in absorption and the change in the refractive index through the Pockels effect. By applying a field perpendicular to the MQW layers, a certain birefringence is induced in this region. By polarising the input beam and looking at the difference in intensity of the two polarised components of the reflected beam, the induced birefringence was calculated as a function of the input wavelength, for various applied electric fields. As a result, we obtained a positive change of the refractive index in the longer wavelength region and a negative change in the shorter wavelength region. It is interesting to note the point where this change becomes zero. It was found that the zero crossing for each applied field was associated with the crossing of the absorption curve for each field and the zero field absorption curve. Therefore, a shift of the zero transition in the refractive index change with applied field was observed. This shift is hence related to the shift observed in the exciton resonances with applied field.

This leads to the interesting idea that this device can act as a phase modulator as well as an amplitude modulator.

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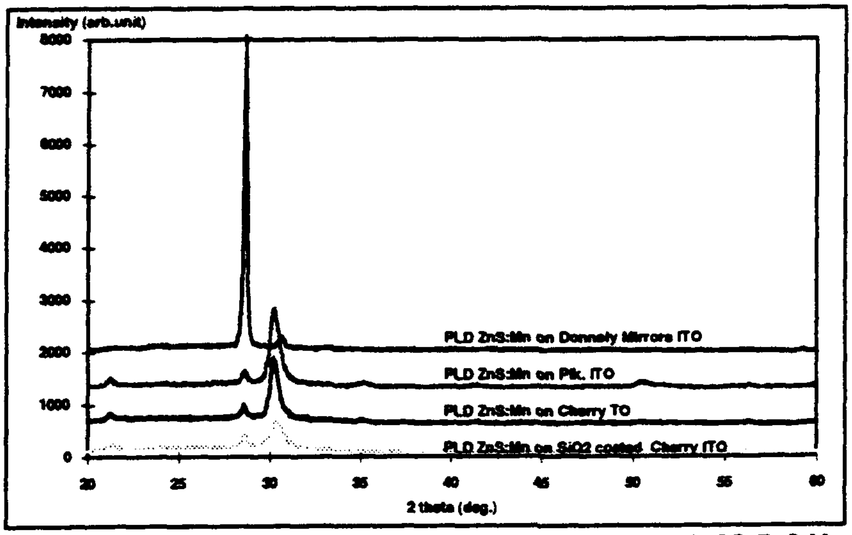

Fig 1. shows the effect of substrate type on the crystal structure of PLD ZnS:Mn.

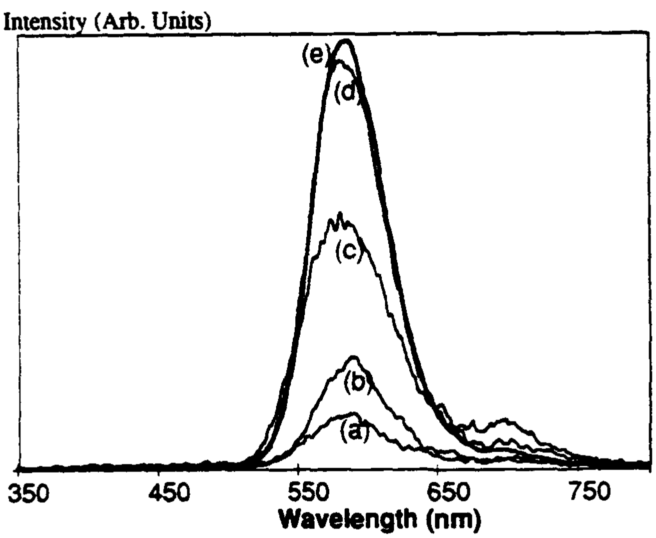

Fig.2 shows cathodoluminescent characteristics for various film thickness(a) 1μ m (b) 2μ m (c) 4μ m. Electroluminescent spectra for (d) RF sputtered and (e) PLD ZnS:Mn thin films.

Properties of ZnS:Mn thin films prepared by 248nm pulsed laser deposition.

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Films of ZnS:Mn are of major interest in optoelectronic applications, particularly for their luminescent properties. Electroluminescent films[1] require well controlled stoichiometry, crystallinity and integrity in order to minimise non-radiative transitions and to support the high electric fields needed for hot carrier excitation of the manganese luminescent centres. Several widely used deposition techniques include RF sputtering[2], electron beam evaporation[3] and atomic layer epitaxy[4], each with its own advantages and disadvantages regarding film quality and deposition rate. A further possible technique involves the vaporization, or ablation, of a ZnS:Mn target by short duration (PLD)[5], high energy laser pulses from a KrF laser, to produce a highly directional flux of energetic target material. Slowed down by a back-filled gas, the material condenses onto a substrate creating the thin film. This technique, operating under vacuum conditions, involves three processes, namely: surface vaporisation, plasma generation and material ejection. The final properties of the deposits depend on the mechcanism of the initial ablation, process vaporization and the subsequent interaction of the plume material with the target.

Good stoichiometric quality and typical luminescent crystal structures have been observed with a predominant hexagonal phase and little evidence of the cubic phase. A study of crystal structure dependence on substrate type, has produced results suggesting an amorphous type substrate, found in ITO coated corning 7059, is more suitable than crystalline tin oxide coated soda lime glass *(Fig.1)*. The luminescent characteristics were determined by cathodoluminescence (CL) and photoluminescence (PL) excitation and stable electroluminescence was observed under pulsed DC conditions with a minimum brightness of 150cd/m^2 *(Fig2)*. PL and CL spectral output have been studied in order to investigate some of luminescent properties, such as direct excitation of the luminescent centres and how dopant densities effect overall luminescent efficency. Absorbtion characteristics were studied and related to crystal structure and luminescent mechanisms of ZnS:Mn. PLD film characteristics are compared with those observed in RF sputtered samples.

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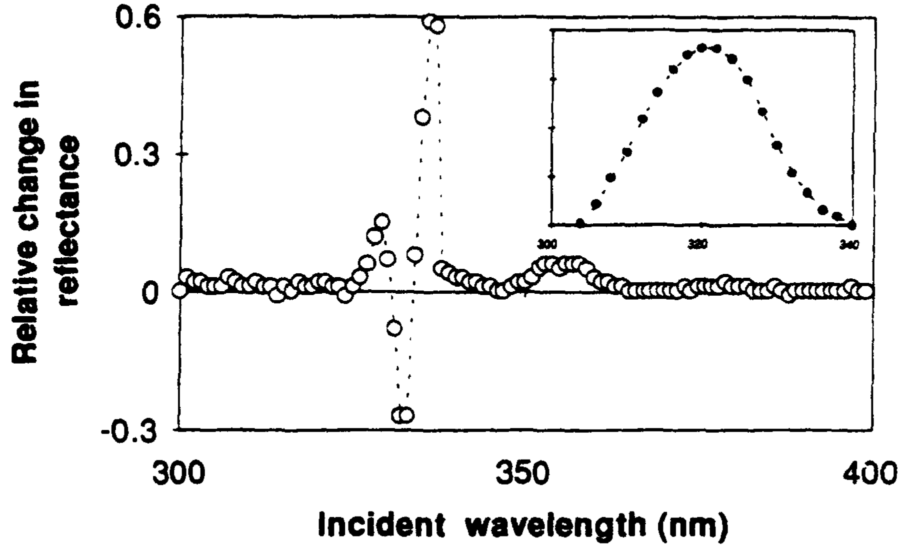

Figure 1. Electroreflectance spectrum. (Inset: Photoconductivity plot)

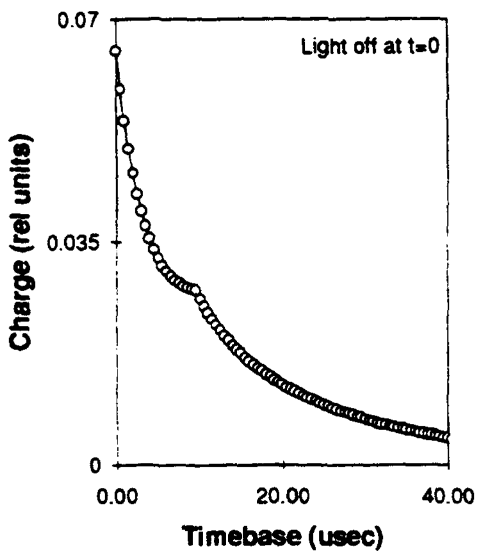

Figure 2. Electroded time of flight. 60μsec W light pulse, 25V.

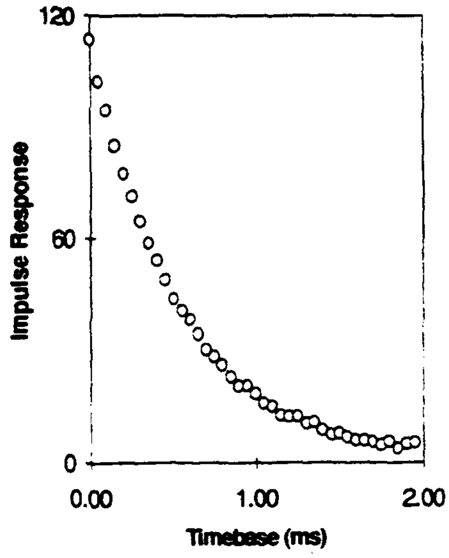

Figure 3. Impulse response by cross-correlation of PRBS input.

THE ELECTRONIC STRUCTURE & TRANSPORT PROPERTIES OF ZnS

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Zinc sulphide is a direct bandgap semiconductor with applications in high field electroluminescent devices and with the potential as an efficient blue phosphor. Advances have, however, been made primarily on an empirical rather than theoretical basis since the development of a suitable quantitive theory is difficult due to the presence of very hot carriers and deep traps. Furthermore there is little experimental data which has been obtained under well defined conditions[1]. ZnS films have been deposited by a range of techniques and device performance can be linked qualitively to growth conditions, crystallinity and stoichiometry. However the fundamental semiconductor properties have not been well characterized[2]. The aim of this work is to develop suitable investigative techniques and to characterize the basic semiconductor properties, such as bandgap, mobility and trap densities, initially at low fields, for a range of deposition methods. This may then form the basis of a model relating the semiconductor and material properties to the light emission characteristics.

The variation in bandgap, under a range of deposition conditions, has been determined from the absorption edge and from photoconductivity dependence upon photon energy. However such techniques have limited potential given their low resolution. High resolution methods, based on electroreflectance spectroscopy, have been evaluated for zinc sulphide, an example of which is shown in figure 1. A fit to the function provides the broadening parameter, order and phase which then allows determination of the bandgap, to within 0.01eV. The use of electroded time of flight analysis (ETOF), to investigate mobility and the effect of bulk traps has been evaluated for zinc sulphide in order to minimize the limitations of surface recombination and relatively high electrode contact potentials. The carrier transit time, figure 2, can be related to the mobility under low, uniform field conditions, whilst the trap density can be determined from the exponential tail. The influence of bulk traps on charge transfer in *MISIM* structures have been investigated[3] by frequency response analysis but results are ambiguous due to the effect of interface states. A novel impulse response technique, suitable for MSM structures, has been developed[4] and has shown first and second order responses, the latter characteristic of deep traps, figure 3.

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TOLERANCE ADVANTAGES OF DIFFERENTIAL OVER SINGLE OPTICAL LOGIC ELEMENTS.

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A major disadvantage in the utilisation of non-linear optical devices in computing has been their relatively poor tolerances to changes in the parameters used to control the device. We observe a marked improvement in these tolerances if two of these devices are linked together and identify two different methods of coupling between the devices. The type of differential logic performed by these coupled devices is shown to be dependent upon the method of coupling used. We apply the differential coupling paradigm to Non-Linear Interference Filters (NLIF's), Liquid Crystals and Self-Electro-Optic Effect-Devices (SEED's). For example the response of the optically coupled NLIF depends upon the difference between the two inputs and the response of the S-SEED, which is coupled electronically, depends upon the ratio of the two inputs.

The devices under consideration are able to produce any of the basis Boolean functions NOR/NAND. We generate a region of acceptability for the NAND function, for each device, by determining the conditions which have to be satisfied for the coupled component to generate the correct outputs. A comparison between the regions of acceptability of the single/coupled BEAT and the single/coupled SEED is made and the coupled devices are shown to be more tolerant of fluctuations in one of the adjustable parameters. A theoretical estimate of the switching times of each device is made and the optimal operating point is determined.

ASYMMETRIC FABRY-PEROT ELECTRO-OPTIC MODULATORS CONTAINING A POLYMERIC FILM

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Many organic polymeric materials have been developed that possess electro-optic coefficients exceeding that of $LiNbO_3$ [1]. These materials lend themselves to incorporation within Fabry-Perot structures to form an electro-optic modulator, with potential for high modulation speeds and a wide range of commercially viable applications which are enabled by their ease of processing.

The objective of TTL compatibility for the drive voltages of such devices requires optimisation of both the optical characteristics, i.e. maximisation of finesse, and the efficiency with which externally applied drive voltages achieve the high fields required for electro-optic modulation.

We have thus designed and modelled a number of asymmetric Fabry-Perot structures based on combinations of metallic reflective layers and dielectric reflectors incorporating an electrode layer. It is shown that high throughput and high contrast modulation for a low drive voltage is optimally achieved with reflection operation rather than transmission.

Taking an r_{13} value of 20pm/V for the electro-optic coefficient of the polymer spacer, and a realistic cavity finesse of ~600, we can thus calculate the drive voltages required for reflection operation and hence show that a 3dB insertion loss and 3dB modulation may be simultaneously achieved with a TTL compatible 5V drive.

Prototype devices incorporating an azo-benzene derived crosslinkable polymeric film [2] have been fabricated and characterised. Optical modulation of 38% has been achieved with a drive voltage of 88V (rms) from an asymmetric design consisting of one thin and one thick gold layer as the front and rear mirrors respectively. The electro-optic coefficients r_{13} and r_{33} were measured using angle-tuning of the resulting cavity to give r_{33} values of 36pm/V at 633 nm and 6.6pm/V at 1.3 μm.

Future improvements in these materials and our fabrication facilities will allow the demonstration of devices with improved contrast and reduced insertion losses, operating at drive voltages comparable with that available on an IC surface.

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Optical and Magneto-Optical Properties of M.B.E. grown Co/Au Multilayers.

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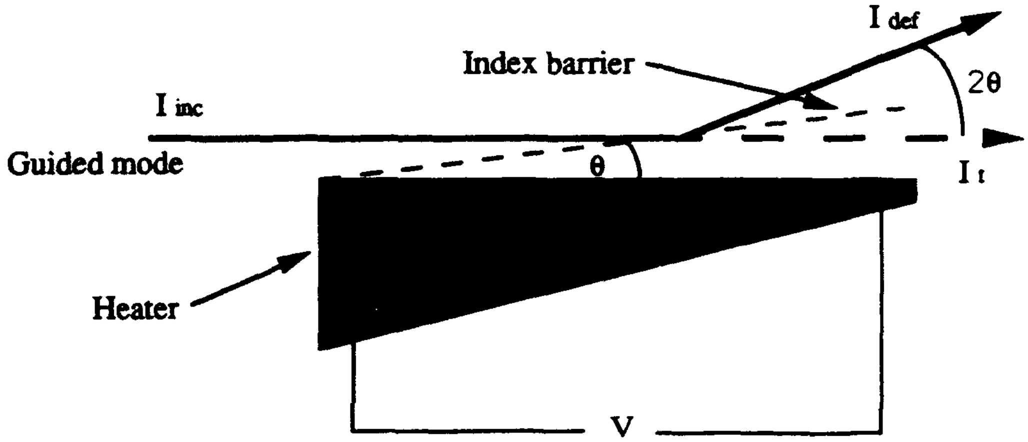
The optical and magnto-optical properties of Co/Au multilayers, grown by Molecular Beam Epitaxy (M.B.E.), have been examined in the wavelength range 300 to 900 nm using a variable angle spectroscopic ellipsometer and a normal incidence Kerr polarimeter. The results of these measurements will be presented together with X.R.D. and Kerr hysteresis studies related to a number of Co/Au superlattices with periods ranging from 15 to 60 nm. The dispersion of the fundamental macroscopic optical and magneto-optical constants and complex polar Kerr rotation will be discussed in terms of the interaction of electromagnetic radiation with a multilayer structure. This is done on the basis of a Single Equivalent Layer (S.E.L.) approach for dealing with multilayered media using values for the optical and magneto-optical constants of cobalt and gold, measured on thick films of these materials, also grown by M.B.E.

A comparison of the results with a simple S.E.L. model indicates that a significant restriction of the mean free path of the conduction electrons in the gold layers, of the order of the individual sub-layer thickness (a few nm), accounts for some aspects of the observed optical spectra.



Principle of operation of Thermo-Optic Deflector

THERMOOPTIC DEFLECTION SWITCHING IN POLYMERIC OPTICAL WAVEGUIDES

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Abstract

A novel optical deflector switch utilising the thermooptic effect is realised in thin film polymeric planar waveguide structures. The guiding layer is fabricated from commercially available polyurethane varnish spin coated onto a suitable substrate. The device employs a tapered metallic stripe heater, which, when a small voltage is applied, produces a thermally induced refractive index gradient in the guiding region. With no applied voltage, the guided beam propagates undeflected parallel to the heater. When a small d.c. voltage is applied, the guided mode is deflected through an angle which may be thermooptically controlled via the applied heater voltage. Deflection of the guided mode is based upon refraction at the induced index gradient [1],[2]. Initial device tests show the feasibility of modulating the deflection angle at frequencies of several kHz.

An optimised device, in which the guided mode propagates beneath an electrode structure is also being currently tested, where the deflection in this case is due to differences in optical path length.

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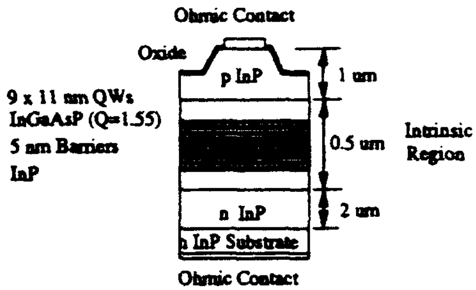

Figure 1 : Proposed waveguide structure

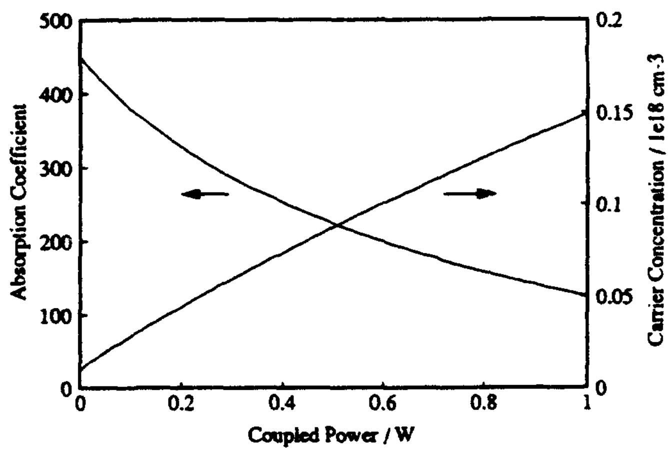

Figure 2 : Theoretical calculation of bleaching of absorption coefficient and carrier concentration as functions of coupled power.

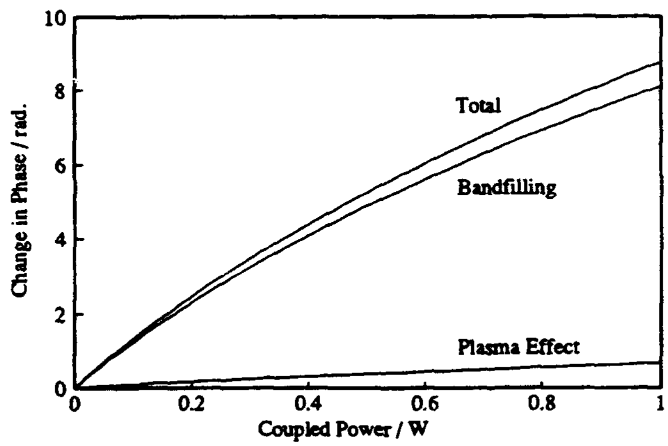

Figure 3 : Theoretical calculation of phase shift as a function of coupled power

THEORETICAL STUDY OF CARRIER ENHANCED REFRACTIVE NONLINEARITIES IN AN InGaAsP/InP MULTI-QUANTUM WELL ALL-OPTICAL PHASE MODULATOR

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In recent years there has been much interest in all-optical nonlinearities in semiconductor multiple quantum well (MQW) structures. All-optical interferometric modulator/switches, utilising photogenerated carrier induced nonlinearities, potentially offer efficient switching on picosecond time scales [1,2]. Recent experiments have demonstrated self phase modulation of 7.5 radians in an MQW structure due to band tail absorption, using a 30 ps optical pulse with a peak coupled power of 4.3W at a wavelength of 1.53 μm [3].

The observed self phase modulation is due to a combination of several distinct nonlinearities. Until now, no detailed modelling of these results has been carried out. A detailed model has been developed to describe the results [3] and to predict optimised designs for low power operation. The effects of bandfilling and the plasma effect on the waveguide refractive index, due to photogenerated carriers are investigated. In the theory presented here, the total number of carriers generated due to linear and two photon absorption is used to calculate the phase shift due to the plasma effect. The change in refractive index due to the change in absorption coefficient caused by bandfilling is calculated by numerically solving the Kramers-Kronig relation. Good agreement has been found between theory and the reported experimental results. The theory assumes that no recombination (either spontaneous or stimulated) of carriers occurs during the optical pulse and that all carriers have recombined before another optical pulse is incident on the waveguide. It is also assumed that the initial linear absorption coefficient, α, is small so that the number of photo-generated carriers does not cause α to fall close to zero.

Using this model, an InGaAsP/InP multi-quantum well waveguide structure, optimised for use as a phase modulator, is studied to predict its phase modulation performance. The waveguide layer structure, shown in figure 1, consists of nine, 11 nm InGaAsP (Q=1.55) quantum wells lattice matched to InP barriers of width 5 nm. The predicted phase modulation is shown in figures 2 and 3. Figure 2 shows the calculated carrier concentration rises to $1.5\times10^{17}cm^{-3}$ for a coupled power of 1W, and bleaching of the linear absorption coefficient. Figure 3 shows the predicted phase shift, due to bandfilling and the plasma effect, to be in excess of π radians for a coupled power of 300 mW. A phase shift of π radians is the required phase shift for the operation of an interferometric switch. The power necessary to induce the refractive nonlinearity is of the order of that capable of being produced by laser diodes [4], making this route to all optical switching an attractive possibility for telecommunications systems. Experimental results will be presented at the meeting.

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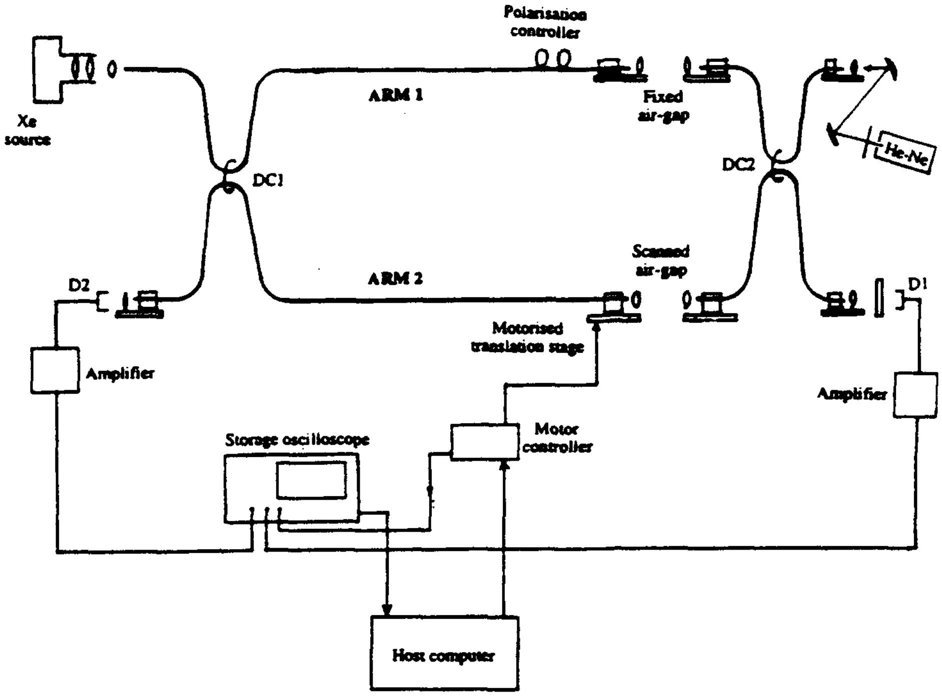

Fig 1. The experimental configuration.

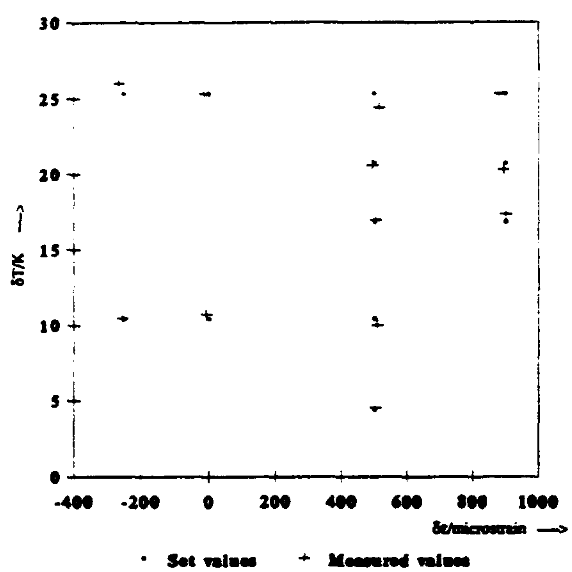

Fig 2. Comparison of set values of temperature and strain with the values measured interferometrically

INTERFEROMETRIC FIBRE OPTIC SENSOR BASED ON DISPERSIVE FOURIER TRANSFORM SPECTROSCOPY.

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Optical fibre interferometry has been applied extensively in physical sensing. An important application is the measurement of strain, via change in the optical phase of the fibre guided beam. However performance is compromised by cross-sensitivity to temperature. Furthermore signal processing is complicated by the periodic nature of the interferometer transfer function. In this paper we describe a new type of fibre-sensor based on dispersive Fourier transform spectroscopy (DFTS). The sensing element forms part of one arm of a two-beam interferometer, illuminated by a broad-band source. We illustrate the concept in the simultaneous measurement of temperature and strain, without fringe order ambiguity.

A Mach-Zehnder interferometer with an Xe arc lamp source and a scanned air path is used (**Fig 1**). DFTS allows determination of the phase values at a number of optical frequencies across the source spectral range, thus yielding a set of extended parameters for analysis. This analysis leads to unambiguous, well-conditioned and simultaneous determination of temperature and strain.

A fixed length of the fibre in arm A of the interferometer is subjected to changes in temperature and strain and an interferogram is detected as the air path is scanned through the region of zero path imbalance. The argument of the positive frequency half of the Fourier transform of the interferogram equals the interferometric phase difference. Expansion of this phase around a central optical frequency yields a set of coefficients characteristic of the induced changes in the phase and its derivatives with respect to frequency. These coefficients then constitute a vector characteristic of the response to the imposed changes in temperature and strain. These coefficients, with the exception of the zeroth-order coefficient, are not subject to phase ambiguity. They are directly related to the imposed changes in the group delay, first and higher order dispersion of the sensing element.

The temperature and strain are related to the characteristic vectors via a transfer matrix. Hence the temperature and strain may be simultaneously recovered from the measurement of a single characteristic vector.

Results showing the simultaneous and unambiguous determination of strain and temperature in the ranges of 1500 micro-strain and 25 K are presented in **Figure 2.** Typical accuracies obtained were ± 10 micro-strain and ± 0.5 K respectively

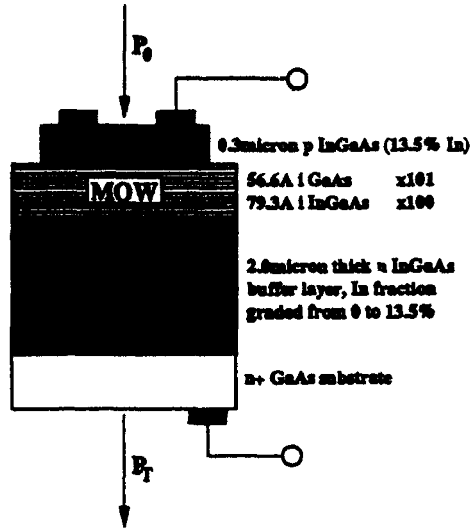

Fig. 1 Structure of relaxed strain-balanced InGaAs/GaAs MQW SEED modulator designed to have exciton absorption peak at 1047nm

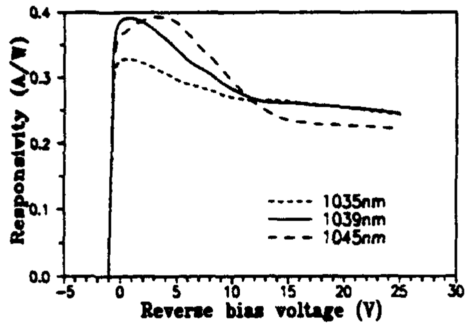

Fig. 2 Room temperature photocurrent responsivity of modulator. Note: exciton absorption found experimentally to be at 1039nm

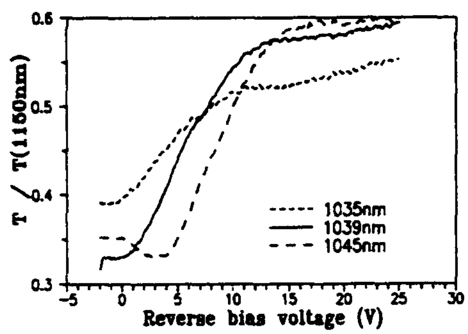

Fig. 3 Room temperature optical modulation performance of modulator. Vertical axis shows transmission normalised to that at 1150nm

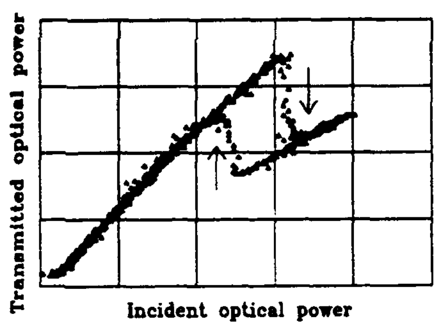

Fig. 4 Measured bistable performance of device connected as an R-SEED, with external resistor and 50V supply voltage

Strain-balanced InGaAs/GaAs SEED modulators for 1047nm

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Optical computing demonstrators based on GaAs/GaAlAs self electro-optic effect device (SEED) arrays operating at around 850nm are usually driven by 50mW laser diodes. Much greater system bandwidths could be obtained if higher power (e.g. 10W) lasers could be used. The most appropriate laser would be diode-pumped Nd:YLF, operating at 1047nm with a good spatial mode, but no ternary semiconductor which is lattice matched to either InP or to GaAs has its fundamental absorption feature at this wavelength. We have investigated InGaAs/GaAs strained quantum wells on a (transparent) GaAs substrate which can be used to make reverse biased *pin*-diode SEED photodetector-modulators for 1047nm. The *i*-MQW region must be 1-2μm thick in total. To make such a thick region mechanically stable, it is grown on a buffer layer of intermediate indium concentration which has been allowed to relax deliberately. The tensile strain in the GaAs barriers of the MQW is then balanced by the compressive strain in the InGaAs wells and the structure is stable. The difficulty lies in the growth of a buffer structure[1] to obtain the correct lattice constant, while preventing the generation of propagating dislocations which would lead to broadening of the excitonic features and to low photodetector quantum efficiency.

The excitonic peak observed in previous SEEDs made in this system[2,3] was too broad to allow good modulator operation. We have grown a series of InGaAs/GaAs samples on GaAs by MBE to find the optimum growth conditions and buffer structure. A typical device (Fig.1), grown at 570°C (~70°C above the optimum growth temperature), had a high density of misfit dislocations but still had a reasonably narrow absorption peak (7.5meV HWHM) and 99% carrier sweep-out quantum efficiency under the built-in junction field (zero applied bias). Due to the quantum confined Stark effect there was significant reduction in photodiode responsivity (Fig.2) and modulation of the transmission (Fig.3) with increasing reverse bias, enabling us to demonstrate bistable operation when the device was connected in a Resistor-SEED configuration (Fig.4). From the measured responsivity/voltage curve, we calculate that a reflection-mode Symmetric-SEED made from this wafer would have a bistable contrast ratio of 2.9 at 13V bias voltage.

We will report on the behaviour of SEED structures grown at lower temperatures, which should show higher contrast and lower bias operation. We will discuss the integration of InGaAs/InAlAs mirror stacks with these SEEDs and hope to show results on the bistable operation of a reflection-mode device addressed optically through the substrate, with a bias voltage below 10V.

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NONLINEAR JOINT TRANSFORM CORRELATION WITH A GEC-MARCONI OPTICALLY ADDRESSED SPATIAL LIGHT MODULATOR

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Joint transform correlation is an important technique in optical processing and has considerable potential for the interrogation and comparison, in real time, of similar input images. The correlator requires two Fourier transforms; the first transform is recorded as an intensity distribution, for example using photographic film, and the correlation function is produced in the second Fourier transform plane. Real time operation can be achieved by using an optically addressed spatial light modulator (OA-SLM) in the first Fourier transform plane. An input signal incident on the photoconductor of an OA-SLM is read out as an intensity pattern from a liquid crystal layer and the real time performance is governed by the electrical characteristics of the device.

Nonlinear compression of the input intensity by OA-SLMs has been shown to improve the correlation performance compared to a linear joint transform correlator[1]. A novel exploitation of this technique is available with the GEC-Marconi OA-SLM which offers the choice of two different nonlinear modes of operation. Using this device the performance of the joint transform correlator is compared for the two nonlinear modes in terms of variations in the SLM operating conditions, object rotation, object scale change and object separation.

For each of the system variables, the dynamic range within which the correlation strength is maintained, is investigated and defined. Results show that the Fourier lenses have position tolerances consistent with depth of focus calculations. However the dynamic range of the other system variables are found to be larger than expected.

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Optical and Electro-Optical Synchronisation using Laser Diodes

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Semiconductor lasers have found a wide range of applications in optical communications, switching, and information processing. Two-section self-pulsing laser diodes, as device. -oducing short duration pulses at a controllable repetition rate, have recently attracted attention for perfoming such new optical functions 1). One sectionis a gain section and the other an absorber section. In addition it is possible to perform frequency division or multiplication through harmonic synchronisation. All-optical synchronisation can be achieved by injecting a light signal which is intensity modulated at a frequency close to the self-pulsing frequency. This approach has been used to perform all-optical clock extraction at high data rates.

Synchronisation can take place with an electrical input to either section. However experimental investigation has shown that the absorber section is more effective for perfoming electro-optic synchroronisation. In the simplest case a sinusoidal input applied to one of the sections synchronises the self-pulsation frequency to the electrical input frequency. As with an optical input signal, the functions of division and multiplication can also be performed with an electrical input signal. Electro-optic timing extraction can be perfomed if a pseudo-random data signal is applied to the absorber section. We have invetigated this behaviour using actual line transmission equipment from a 565 Mbit/s optical system. Additionally using a signal which is rich in harmonics it is possible to synthesize pulse trains at various repetition frequencies. This is achieved by simply varying the bias to the self-pulsing laser.

In conclusion optical and electro-optical synchronisation offers potential for new applications for laser diodes in communications, information processing and instrumentation.

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AlGaAs-GaAs heterostructures and Resonant Tunneling Diodes: Current-Voltage-Temperature Measurements and Applications.

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We have performed current-voltage-temperature (I-V-T) measurements on AlGaAs/GaAs isotype heterojunctions and fitted the obtained data to a model based on a combination of thermionic emission and diffusion conduction processes. The activation energy data is used to determine the conduction band discontinuity (ΔE_C) at the AlGaAs-GaAs interface. The value obtained, ΔE_C=0.67 ΔE_g, is in agreement with values reported and obtained using other techniques [1,2,3].
Experimental conductance-voltage and current-voltage characteristics of AlGaAs/GaAs double barrier resonant tunneling (DBRT) heterostructure diodes show a shift in the voltage at resonance to larger values than predicted by a simple tunneling conduction model. The voltage shift (ΔV=0.3 V) is partially attributed to the charge build-up inside the well region and the asymmetry of the barriers under an applied bias voltage.
Results on the switching capabilities of DBRT diodes, their equivalent circuit at moderate frequencies and their use as functional elements in three state logic circuits are also presented.

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NOVEL ALGORITHMS BASED ON NEURAL NETWORKS MAY BE USED TO EFFICIENTLY EXPLOIT OPTICAL HARDWARE CHARACTERISTICS

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The interconnection density and bandwidth available in optics is a natural platform on which to conceive neural processors but a lack of suitable devices has held up progress. Most approaches at present attempt to implement known neural models and algorithms in optical hardware. An alternative approach may be to invent new, or adapt old, models and algorithms that map onto optical hardware that exists. In particular the dynamics of devices play an important role in asynchronous networks, and these dynamics may be exploited. We have had considerable success in applying these ideas to e.g. fault tolerant logic units and simple pattern recognition based on non-linear interference filter characteristics [1]. In this paper we particularly consider the changes necessary to our algorithms to enable these tasks to be performed on other classes of devices including SEED based pixels. All our device characterisation is based on measurement and modelling work carried out in the Physics Department at Heriot-Watt University.

The algorithms currently employed are crudely based on error propagation. Emphasis is laid on the desirability of performing all the necessary functionality (particularly the learning feedback), within the optical hardware domain.

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RAMAN SCATTERING STUDIES OF THE $(Al_xGa_{(1-x)})_{0.5}In_{0.5}P$ ALLOY

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Considerable effort in the development of red semiconductor lasers has been directed towards thc $(Al_xGa_{(1-x)})_{0.5}In_{0.5}P$ quaternary alloy as the laser active material. We have found Raman scattering to be a useful characterisation tool for studying changes in this alloy, arising from different growth conditions. Our Raman spectra of the endpoint ternary materials, (GaInP, AlInP) show two-mode longitudinal optical (LO) phonon behaviour. For GaInP, the InP-like and GaP-like LO modes have Raman shifts of 360 and 380 cm^{-1}, respectively, from the exciting laser line. For AlInP, the InP-like and AlP-like LO modes appear at 340 and 460 cm^{-1}, respectively. A significant enhancement, greater than a factor of 10 in Raman signals, has been observed for some AlInP samples using different laser wavelengths provided by an argon ion laser. From this data, an approximate resonant enhancement curve can be derived which peaks at 2.54 eV. We attribute this enhancement to resonance with the zone centre band-to-band transition. Resonant Raman scattering from samples whose surface morphology is poor also occurs, although the character of the enhancement band varies accordingly; therefore, the Raman behaviour provides useful information on material quality.

Characterisation of these ternary alloys, grown by metalorganic vapour phase epitaxy (MOVPE), show that either an ordered or disordered phase may exist depending on growth conditions. We have used the Raman technique to investigate the degree of disorder found in these compounds. Raman spectra of the quaternary alloy exhibit three LO phonon modes, namely InP-like, GaP-like and AlP-like modes. The Raman shifts and intensities of these modes vary with Al composition. We have correlated this behaviour in the quaternary alloys with room temperature photoluminescence. The results outlined here clearly demonstrate the value of the Raman probe in the characterisation of these new materials, particularly when investigating indirect quaternary alloys where the use of photoluminescence is no longer possible.

INVESTIGATION OF TRAPPED ION DYNAMICS BY PHOTON CORRELATION AND PUMP-PROBE TECHNIQUES.

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Recent experiments using quadrupole ion traps have shown that, under the influence of strong laser cooling, the ions can form into ordered structures. For small numbers of ions, crystals with very large inter-ion spacings are formed. Such crystals can be held stationary in a Paul trap and have been imaged [1]. It is not possible to image individual ions held in a Penning trap since the cloud rotates about the centre of the trap at the magnetron frequency ($\omega_m \sim 50$ kHz).

We have developed two techniques for studying the dynamics of trapped ions. The first is a method for measuring all the ion oscillation frequencies for all types of quadrupole ion trap [2]. Oscillating ions move in and out of the laser beam (and in and out of resonance via the Doppler effect). This leads to the fluorescence being modulated at the oscillation frequency. For small clouds the modulation frequency can be extracted from a spectrum of delay times between consecutively detected photons. Such a spectrum in general contains all the frequencies of interest together and so, to disentangle these, we take a Fourier transform of the spectrum. This method has advantages over the conventional driven oscillator method [3] in that it is non-invasive, measures all the frequencies at the same time and is capable of measuring shifts in the frequencies that result from space charge effects.

The second method measures the magnetron frequency in the Penning trap and uses a pulsed laser in addition to the cw cooling laser. The pulsed laser 'tags' a small portion of an ion cloud by promoting the ions in that portion into a metastable state. Whilst in this state the ions do not interact with the cw laser. As the cloud rotates the tagged portion moves in and out of the cw laser beam and so the level of fluorescence shows dips at a frequency related to ω_m. We have shown that this method can work for larger clouds than can be studied using the photon correlation technique. Furthermore, it can be used to measure ω_m for clouds with much larger values of the space charge shift.

We will present our recent results at the conference and show preliminary data which suggest that the photon correlation method may also be used to infer the presence of small crystals in a Penning trap.

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PICOSECOND TIME-RESOLVED RESONANCE RAMAN SPECTROSCOPY IN THE STUDY OF VIBRATIONAL MODE-SELECTIVE EFFECTS OF SINGLET EXCITED *TRANS*-STILBENE

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A high repetition rate (4.46 kHz) picosecond laser system for time-resolved resonance Raman spectroscopy is presented. The stabilised probe beam is tunable from 550 nm to 655 nm and the pump beam is generated by frequency doubling the probe beam. Pulse energies at the sample are >1 μJ/pulse (probe) and >0.2 μJ/pulse (pump). The apparatus has been used to study the Raman spectrum of singlet excited *trans*-stilbene. Mode-selective changes in the Raman spectra involving peak shifts and broadening are observed over a period of 40 ps after the excitation pulse. The changes were dependent on the pump wavelength, the solvent (n-hexane, hexadecane and an aqueous micelle (Triton-X100R) were studied) and on deuteration of the *trans*-stilbene. Similar changes in width and peak position of the Raman bands has been induced by heating the solvent. The mode-selective changes and dynamics lead to a mechanistic model involving intramolecular vibrational relaxation, re-orientation of the *trans*-stilbene and micro-environment and inter-molecular energy transfer.

LUMINESCENCE MEASUREMENTS ON CONJUGATED ORGANIC MATERIALS

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Abstract

Methid II (4b) and 1-POP-PPVTV are conjugated organic materials which exhibit measurable luminescence.
Photoluminescence measurements were made on dilute solutions in various organic solvents and on thin films spun onto glass substrates.
In both cases the investigated samples show broad emission bands with emission maxima lying in the range 550 - 560 nm and large Stokes shifts of 100 - 110 nm.
A comparison of these luminescence spectra with well-known organic dyes like Rhodamine 6G or Rhodamine B gives an idea of photoluminescence quantum yields; for the investigated materials they lie in the area of 1 %.
Excited state lifetime measurements were carried out using a time-correlated single photon counting technique (TCSPC). The results range from 200 to 300 ps in solution; in thin films a second lifetime at about 5 - 6 ns is evident.

Further measurements like recording low-temperature-spectra or investigating electroluminescence are in progress.

A FLUROESCENCE-LINE-NARROWING STUDY OF POROUS Si,

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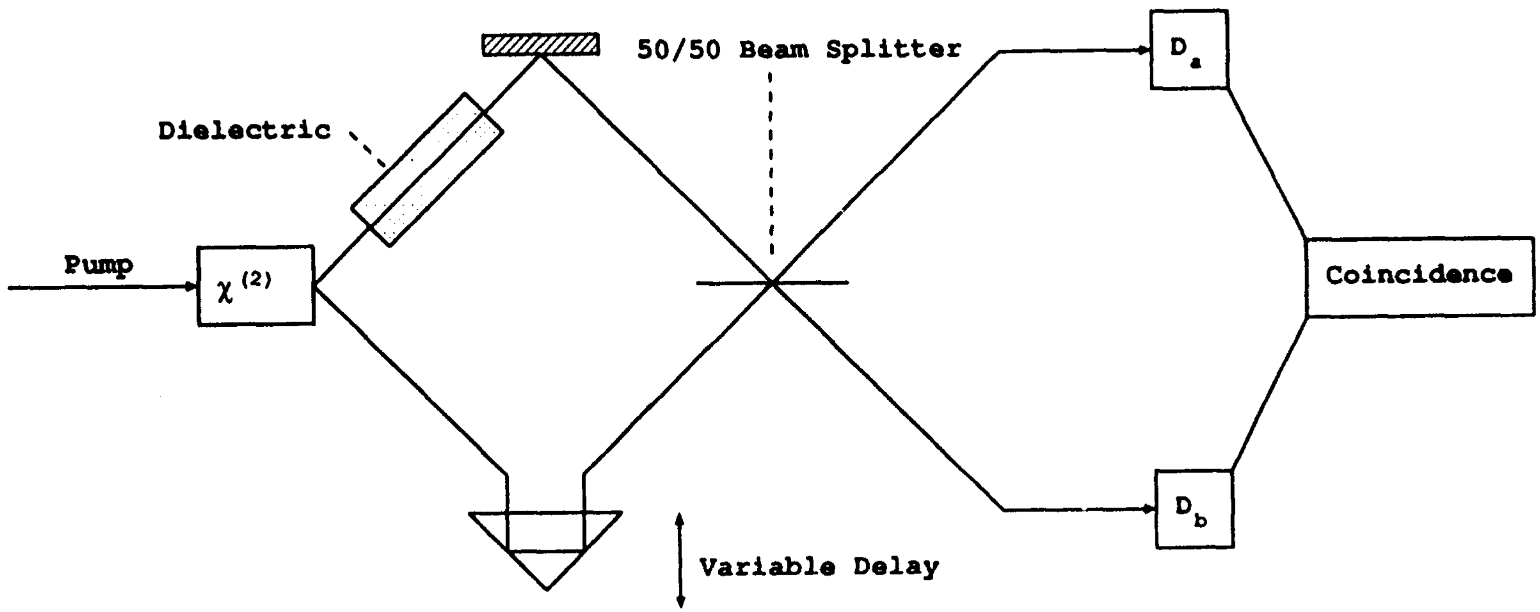
We have carried out an initial investigation of porous-Si luminescence using the fluorescence-line-narrowing (FLN) technique. This technique has proven very successful in elucidating the spectral details of other broad-band systems notably transition-metal-ion doped glasses [1]. We observe a shift and narrowing of the porous-Si emission under the FLN conditions for the first time.

The porous-Si samples were prepared under anodic conditions with a HF concentration of 16%, a current density of 35 mA/cm^2 and etching time of 5 minutes. The samples were placed in a closed cycle cryostat, and the luminescence was excited using a UV Ar^+ laser and dye-laser tunable from 570-790 nm.

Our results show that inhomogeneous broadening is responsible for the large width of the porous-Si emission band. We are now investigating the effects of both resonant and non-resonant FLN on the porous Si emission and the consequence for the quantum confinement and siloxene models for the porous Si luminescence.

[1] F.J. Bergin, J.F. Donegan, T.J. Glynn and G.F. Imbusch, J. Lumin. **34**, 307, (1986).

Figure 1


Dielectric
Pump
$\chi^{(2)}$
50/50 Beam Splitter
Variable Delay
D_a
D_b
Coincidence

QUANTUM PROPAGATION THROUGH LINEAR DEVICES

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Absorption and dispersion in a dielectric medium are related phenomena. They are linked to one another via the Kramers-Kronig relations. This paper first investigates the combined effects of absorption and dispersion in dielectrics on quantum states of light. It uses a recently developed formalism for canonical quantisation of the electromagnetic field in dielectrics [1]. The quantised system is exactly diagonalisable, and it provides for the definition of polariton creation and annihilation operators within the medium.

Entangled photon pairs are quantum states of light which can be produced in $\chi^{(2)}$ crystals. They consist of two photons whose individual frequencies are not well-known but the sum of which is accurately determined. A nonlocal cancellation of the dispersion experienced by the state during propagation through two different media means that the temporal width of the two-count detection distribution need not be affected [2]. When the effects of absorption are included the nonlocal sum of the second derivatives of the absorption coefficients in the two media can cause the temporal width of the two-count distribution to be shorter than it was originally. The loss also affects the delay time acquired by the photons during propagation.

In a fourth order interference experiment using such an entangled state [3,4] (Fig.1), the absorption alters the width of the coincidence count null. It does not, however, change the propagation delay time. For frequency-dependent absorption the detection of a photon pair can provide which-way information about the photons, thus washing out the interference and reducing the visibility of the null.

We also consider the effects of filtering, absorption and dispersion on a multimode squeezed state. The phenomena encountered here are more complex, particularly when correlations between different space-time points in the beam are considered.

Finally, we adapt the dielectric formalism to describe a canonical theory of an optical amplifier. Previous models of the amplifier have been more phenomenological in nature [5]. The propagation of quantum states along this device and the effect upon their statistics are studied.

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ON THE ORIGIN OF LASING WITHOUT INVERSION

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We analyze the physical origin of inversionless amplification in driven two-, three- and four-level systems and identify two fundamentally different mechanisms for the predicted gain. The first mechanism is linked to the existence of a hidden inversion in the dressed state basis, whereas the second is purely based on atomic coherences in both bare and dressed state basis. Special emphasis will be put on the Raman scheme, where both mechanisms can be rendered dominant in dependence on the atomic relaxation parameters. Our method involves the evaluation of the off-diagonal matrix-elements of the density operator which drive the laser field. We then seperate the contributions to the netabsorption due to the inversion of populations and due to the low-frequency coherences in both bare and dressed basis. In the bare state basis, gain always arises from the low-frequency coherence as the populations are not inverted. In the dressed state basis, however, the gain without inversion of the bare states can be due to the inversion of dressed states or due to low-frequency dressed coherences in dependence on the system under investigation. These two fundamentally different situations are associated with two different mechanisms of non-inversion gain and are shown to be understood in terms of population trapping and quantum interference.

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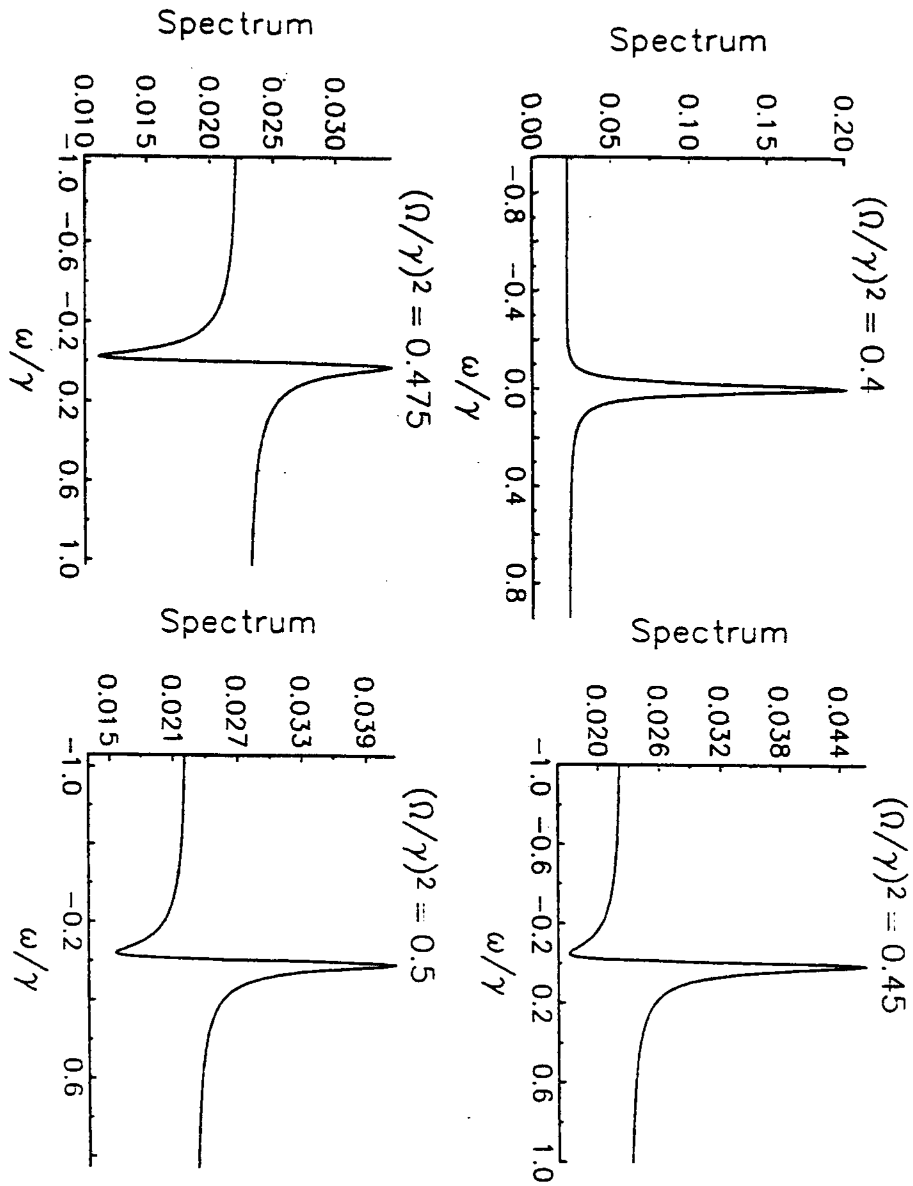
Spectrum
(Ω/γ)² = 0.4
ω/γ
Spectrum
(Ω/γ)² = 0.45
ω/γ
Spectrum
(Ω/γ)² = 0.475
ω/γ
Spectrum
(Ω/γ)² = 0.5
ω/γ

DISPERSIVE PROFILES IN THE RESONANCE FLUORESCENCE OF A TWO-LEVEL ATOM IN A SQUEEZED VACUUM

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We report unusual features in the resonance fluorescence (R. F.) spectrum of a two level atom interacting with a classical resonant field and a squeezed vacuum. The classical field has to be of intermediate strength—too weak for Rabi oscillations to occur, but sufficiently strong for the spectra to have a pronounced dependence on the squeezing phase Φ. The spectra have a *dispersive* profile, quite unlike any seen in resonance fluorescence previously. Not surprisingly, they occur in a parameter range which has received little attention previously, namely a Rabi frequency Ω equal to $1/\sqrt{2}\times$ the spontaneous decay rate, γ, and a value of the squeezing phase of $\pi/2$. They are apparent only over a very narrow range of Rabi frequencies about this value. The figures plot the incoherent part of the R. F. spectrum against frequency, and they show the appearance of dispersive profiles as $(\Omega/\gamma)^2$ varies from 0.4 to 0.5. For $(\Omega/\gamma)^2 \geq 0.525$, the dispersive features have disappeared.

An analytic theory is presented which explains these features, and it is shown that the presence of two distinct spontaneous decay rates, which is a well known property of the interaction of squeezed fields with atomic systems, is necessary for their existence. We emphasize that the squeezed field is essential for the observation of these effects—they are a manifestation of the interaction of non-classical light with atomic systems.

Furthermore, we show that the dispersive R. F. spectra are produced by different atomic correlations to those which produce "normal" R. F. spectra. Normal spectra arise from the diagonal correlations

$$\langle \sigma_1(t)\,\sigma_1(0) + \sigma_2(t)\,\sigma_2(0)\rangle$$

whereas dispersive spectra arise from the off-diagonal correlations

$$\langle \sigma_2(t)\,\sigma_1(0) - \sigma_1(t)\,\sigma_2(0)\rangle\,.$$

We also investigate the dispersive spectra for off-resonant excitation.

ULTRA-HIGH HARMONIC GENERATION EXPERIMENTS AT IMPERIAL COLLEGE

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The new generation of short-pulse high-intensity chirped pulse amplification lasers now available to experimentalists have allowed intensities up to 10^{18} Wcm^{-2} to be produced by laboratory scale systems. One of the high points of the "new" physics produced by such lasers has been the observation of very high harmonics of the fundamental. Ultra-high harmonic generation has attracted considerable interest in the last few years, and much of the work in this area has concentrated on producing higher harmonics at ever shorter wavelengths. Harmonic orders well in excess of 100 at wavelengths down to 76 Å have now been observed by several groups. However if high harmonics are to be used as a source of short-pulse, high-brightness coherent xuv radiation for applications such as spectroscopy or materials probing, a number of issues including their temporal and spatial behaviour need to be addressed.

Laser intensities high enough to produce harmonics in gas jet targets also give rise to rapid multiphoton ionisation. This generates free electrons and depletes the neutral atoms which are believed to account for most of the harmonics seen thus far. Free electrons can couple to the ponderomotive potential of the laser, and as result the harmonic generation process can involve aspects of laser plasma interactions such as channelling and self focusing. This is in addition to the more obvious response of single atoms to an intense laser field, and the macroscopic phase matching of the fundamental and harmonic beams.

Experiments at Imperial College aimed at studying some of the important physics issues in the high harmonic generation process will be described. These will include observations of the angular distribution of harmonics up to the 123rd order produced by a 1 J, 1 ps Nd:glass CPA laser system focused to intensities up to $4x10^{14}$ Wcm^{-2} into a mach 5 helium gas jet. The far field distribution of multiple harmonics was recorded on a single shot basis using a flat field xuv spectrometer coupled to channel plate and intensified CCD camera. Harmonics well into the plateau region were seen to be collinear with the fundamental and to have a much broader angular distribution than predicted by perturbation theory. This is not unexpected, as this is clearly a highly non-perturbative regime. More surprisingly however the highest harmonics observed just before the plateau cut off showed a marked decrease in angular extent, and converged to the width predicted by simple lowest order perturbation theory.

X - RAY LASERS : PROGRESS AND PROGNOSIS

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During the last decade significant progress has been made at several laboratories around the world in generating amplified spontaneous emission (ASE) at wavelengths as short as $\lambda \approx 4$ nm from laser-produced plasmas. A brief overview of recent developments and achievements will be given and future trends discussed.

In particular, some emphasis will be given to work carried out using the VULCAN and SPRITE high power optical lasers at the Central Laser Facility by a consortium of UK university groups.

Among the most recent highlights has been the successful demonstration of an injector-amplifier geometry in which the output ASE beam from one neon-like germanium plasma amplifier is injected into a separate amplifier using a normal incidence, concave X-ray mirror with a total beam relayed distance of ≈ 1.2 meters. This system can, in principle, produce spatially coherent beams with megawatt power levels at soft X-ray laser wavelengths in the range $\lambda \approx 15$ - 25 nm. Preliminary work relating to monitoring the characteristics of such beams will be presented and near-term applications, including holographic imaging, discussed.

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Andor Technology Ltd was formed in July 1989 to develop and manufacture light measurement products. The company was founded by students and staff of The Queen's University of Belfast Physics department and the US based company Oriel Corporation.

Andor has developed a range of 1- and 2-dimensional detection systems which are marketed world wide. Marketing in the US is handled by Oriel Corporation and elsewhere by their representatives. The systems are sold under the product name InstaSpec.

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The InstaSpec CCD system is the first truly portable scientific CCD detection system. To achieve this portability we use the most recent family of CCDs which incorporates a technology known as MPP. This reduces the dark current per unit area by a factor of 10, compared to conventional CCD detectors, allowing us to produce a compact scientific CCD camera which does not require liquid nitrogen cooling. The CCD detectors are also special in that the readout register is along the long dimension. This allows the CCD to be binned along the spatial direction eliminating the need for a shutter in 1-dimensional spectroscopy. An X-ray version of the CCD system is also available.

Andor is currently developing complete systems for spectro-radiometric and Raman measurements.

The Industrial Research & Technology Unit (IRTU) is a subsidiary of the Department of Economic Development. It has responsibility for encouraging and supporting industrially related innovation, research & technological development. IRTU provides information, advice, financial assistance and a wide range of technological testing & analytical services.

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Northern Telecom has 58,000 employees world wide and had 1992 revenues of US$8.41 billion. It invests approximately 11% of its annual turnover in research and development activities.

The organisation has five marketing regions: Canada, US, Caribbean and Latin America, Asia/Pacific and Europe. The Company's R&D subsidiary is called BNR, which has 8700 employees world-wide including 1500 in Europe. NITEC (NT's Northern Ireland Telecommunications Engineering Centre) has 170 employees in Monkstown, and is now managed through BNR.

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In March 1991, Northern Telecom integrated STC plc into its existing European operations to form Northern Telecom Europe Limited, headquartered in London, UK with sales and marketing operations across Europe, the Middle East and Africa. NT (NI) Limited is the Northern Ireland subsidiary.

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Research and development is conducted, by both NT and its R&D subsidiary, at facilities in France, Turkey, Germany, the Republic of Ireland and the United Kingdom.

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